AKTU B.TECH

SEM-3 EE & ALLIED

EMI – ELECTRICAL MEASUREMENTS & INSTRUMENTS

UNIT-1 ONE SHOT

COMPLETE NOTES | AKTU PYQs | IMPORTANT QUESTIONS

Syllabus

UNIT I

ELECTRICAL MEASUREMENTS & INTRODUCTION TO MEASURING INSTRUMENTS: Measurement system, Characteristics of instruments, Methods of measurement, Errors in Measurement & Measurement standards, Classification of Instrument – deflecting, controlling and damping torques – Ammeters and Voltmeters – PMMC, moving iron, Electrostatic, induction type instruments – expression for the deflecting torque and control torque – Errors and compensations, extension of range of instruments.

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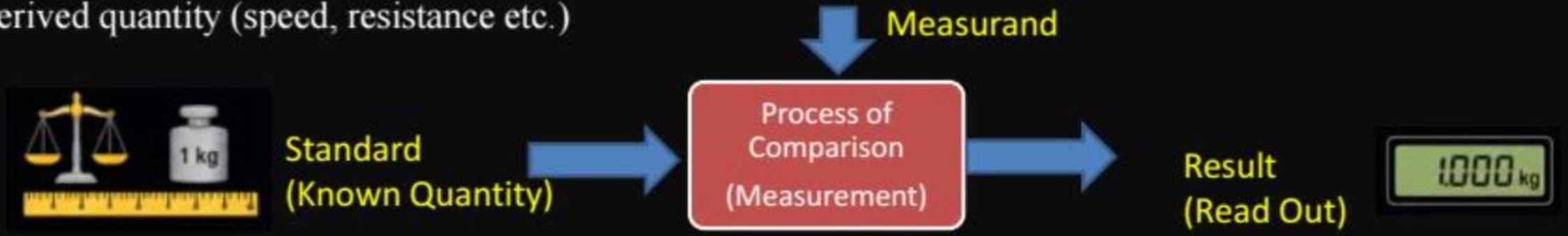
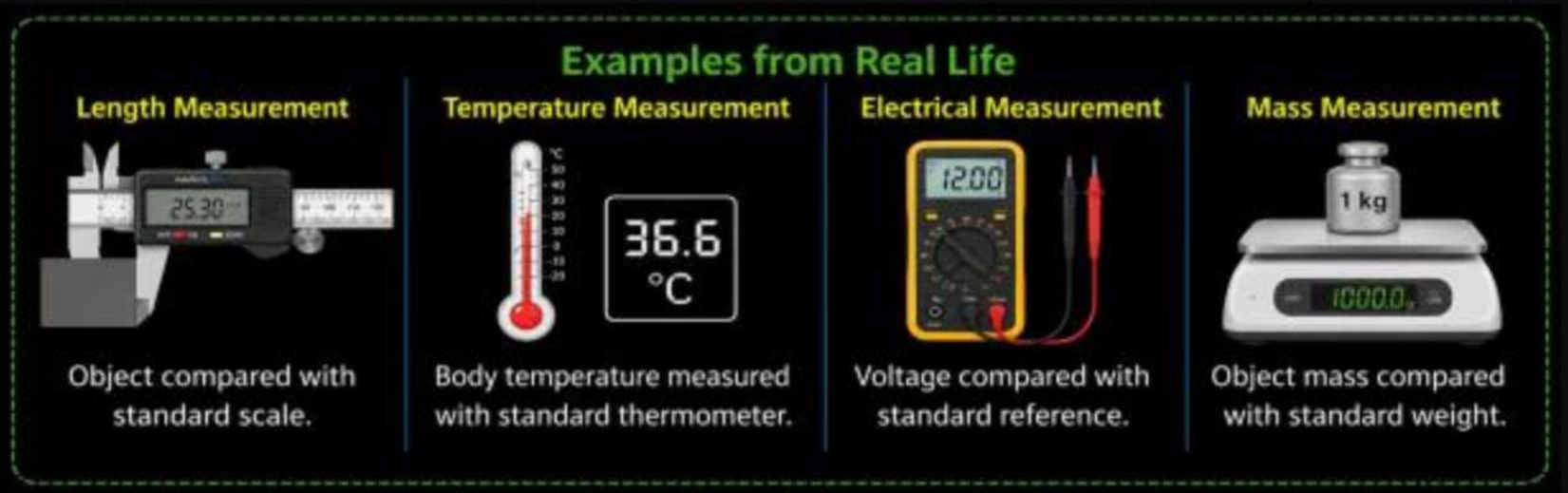
Measurement:- The measurement is the result of the ***comparison of standard and the unknown quantity***. The result of the measured quantity is generally expressed in numeric forms. In other words, the measurement is the process through which the physical parameters like heat, displacement, force etc. is converted into the easily readable numeric value.

Quantity to be measured is known as ***measurand***. It may be fundamental quantity(length , mass etc.) or derived quantity (speed, resistance etc.)





Methods of Measurement

Direct Method: In this method of measurement, the unknown quantity is directly compared with the standard quantity. The result of the quantity is expressed in number and unit . It is the most common method of measuring the physical quantities like length, temperature, pressure, etc.

Ex.- Digital voltmeters, Digital thermometers, and pressure gauges.

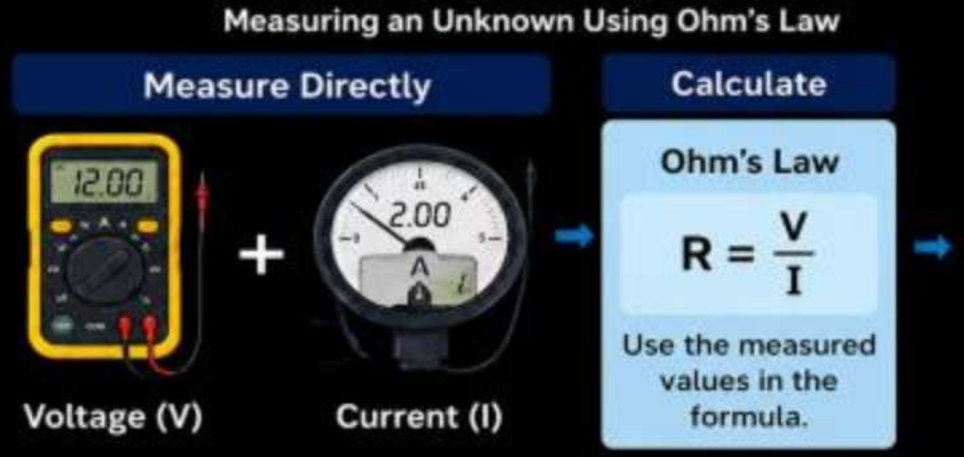
Indirect Method: The Indirect Method of measurement uses an indirect relationship between the quantity being measured and another quantity that is more easily measured.

- The Indirect Method of measurement often requires additional calculations or estimations to obtain the final value.
- **Ex-** Measuring the resistance etc.

Directly measures pressure.

Digital Thermometer °C

Directly measures temperature.



Classification of instruments

An instrument is a device in which we can determine the magnitude or value of the quantity to be measured.

(i) Absolute Instrument **(ii) Secondary Instrument**

(i) Absolute Instrument:-

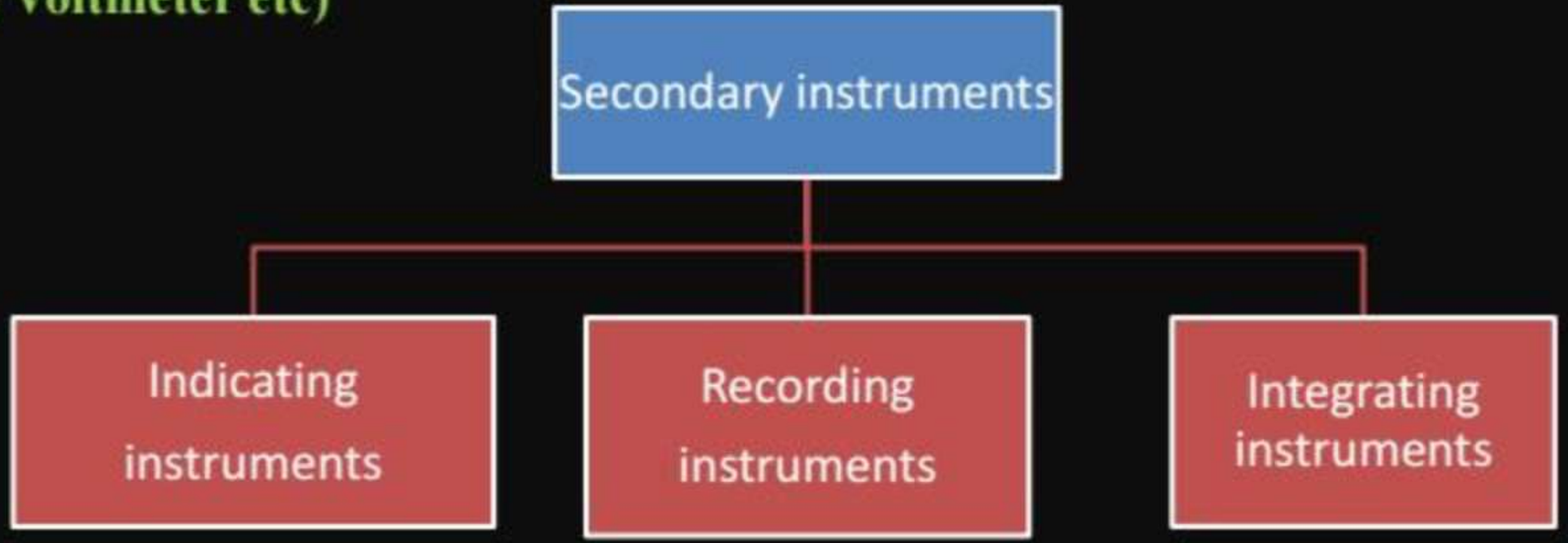
- An absolute instrument determines the magnitude of the quantity to be measured in terms of the instrument parameter.
- This instrument is rarely used, because each time the value of the measuring quantities varies.
- So we have to calculate the magnitude of the measuring quantity, analytically which is time consuming.
- These types of instruments are suitable for laboratory use.

Example: Tangent galvanometer (magnitude of current passes through the coil determines by the tangent of the angle of deflection of their coil)

Secondary Instruments

(ii) Secondary Instrument:-

- In the secondary instrument, the deflection shows the magnitude of the measurable quantities.
- The calibration of the instruments with the standard instrument is essential for the measurement.
- The output of this type of device is directly obtained, and no mathematical calculation requires for knowing their value.
- **Ex. (Ammeter, Voltmeter etc)**



GATEWAY CLASSES

Types of Secondary Instruments

GATEWAY CLASSES

01

INDICATING INSTRUMENT

This instrument uses a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity.

Ex. Ammeter, Voltmeter

02

RECORDING INSTRUMENT

This type of instruments records the magnitude of the quantity to be measured continuously over a specified period of time. In such instruments a pointer leave traces on graph by using pen.

Ex. Chart Recorder, Data Logger

03

INTEGRATING INSTRUMENT

This type of instrument gives the total amount of the quantity to be measured over a specified period of time.

Ex. Energy Meter

Types of Instruments

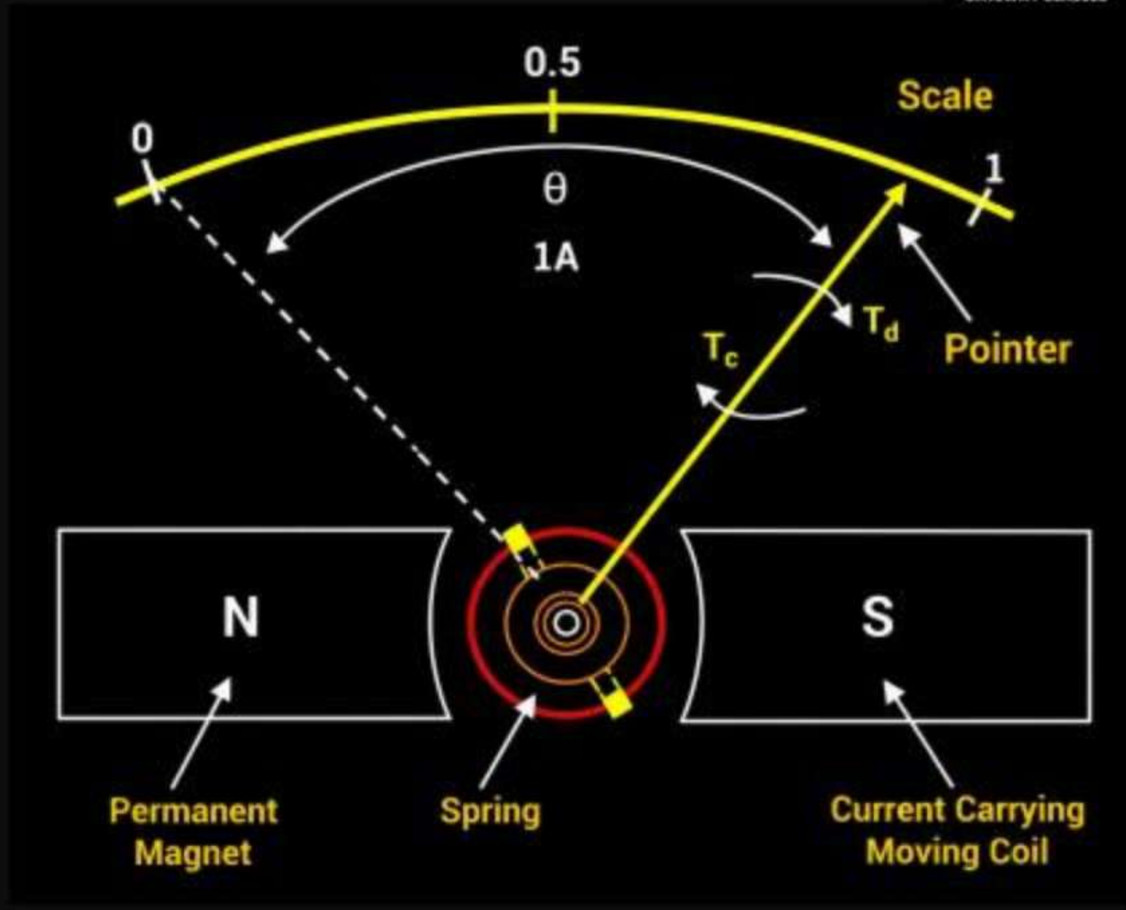
Depending on the way **electrical instruments** present results of measurements they can be classified into 2 major categories.

1) Deflection type instruments

2) Null type instruments

1) Deflection type instruments:-

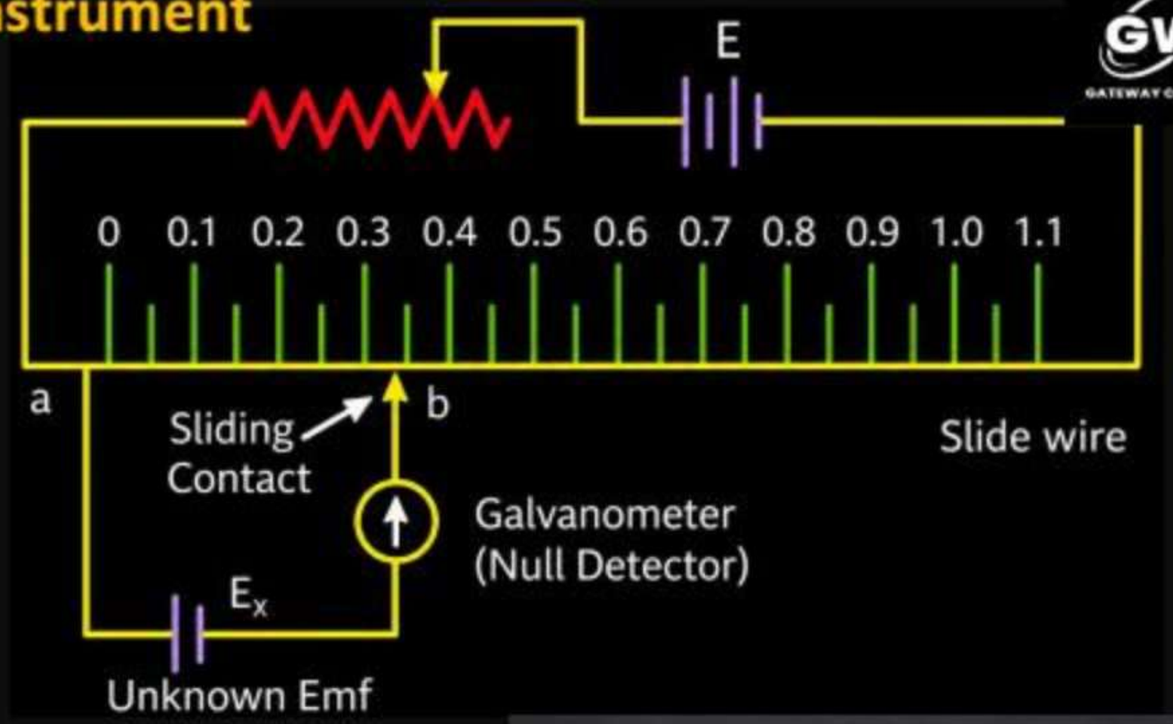
the instrument in which the deflection **provides the basis** for measuring the **electrical quantity** is known as the deflection type instrument. The deflecting type instrument has opposite effects which oppose the displacement of moving systems.



The opposite effect is so designed that their magnitude increases with the increases in the deflection or displacement of the moving system which is caused by the measuring quantity. The balance is attained when the opposite effects are equal to the cause of producing the deflection or movement of moving points.

Null type instrument

Null type instruments:- An instrument in which zero or null indication determines the magnitude of measured quantity such type of instrument is called a null type instrument. It uses a null detector which indicating the null condition when the measured quantity and the opposite quantity are same.



For the operation of the null type instrument, the following condition requires.

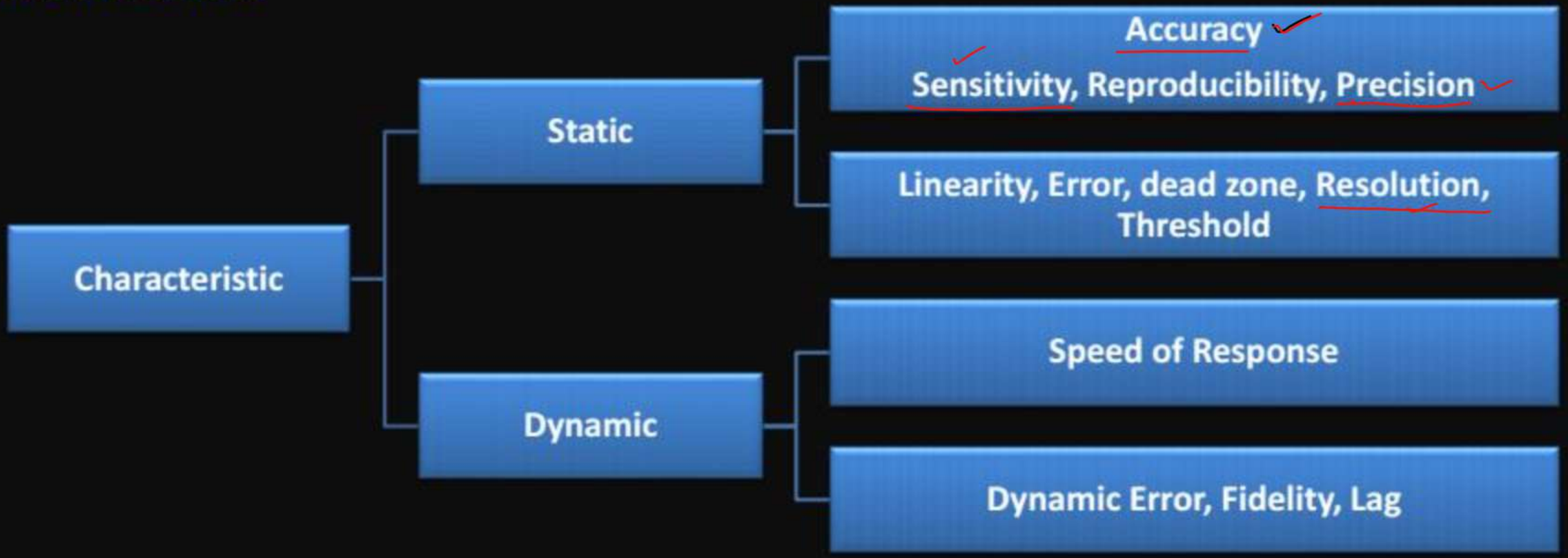
- The effect produced by the measuring quantity.
- The opposing effects whose value are accurately known. It is necessary for measuring the numerical value of the measured quantity accurately.
- A detector which detects the null conditions, i.e., a detector is a device which indicates zero deflection when the balance condition occurs.

Characteristic of Instruments

Performance characteristics of instruments can be classified into the following **two types**.

Static Characteristics

Dynamic Characteristics



Static Characteristics

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Measurement of applications in which the parameter are to be measured are constant or vary very slowly with time are called **static characteristic**. The main characteristics are-

1. **Accuracy:-** The degree of exactness (closeness) of measurement compared to the true value is known as accuracy.
2. **Reproducibility:-** Reproducibility is the ability of a measurement to be duplicated, either by the same person or by someone else under changed conditions.
3. **Precision:-** Precision is the repeated measurement of a set of values relative to each other, rather than the actual value.
4. **Sensitivity:-** It is defined as the ratio of change in output (response) towards the change in input at a steady state condition. It denotes the smallest change in the measured variable in which the instrument respond.

$$Senstivity = \frac{Change\ in\ output}{Change\ in\ input} = \frac{\triangle Ao}{\triangle Ai}$$

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The reciprocal of sensitivity is called deflection factor.

Static Characteristics

5. **Resolution:-** The smallest increment of quantity being measured which can be detected with certainty of an instrument. Thus, the resolution means the smallest measurable input change. **AKTU-2025-26**

6. **Threshold:-** When the reading of an input is increased from zero, the input reading will reach a certain value before change occurs in the output. The minimum limit of the input reading is known as threshold.

7. **Linearity:-** The instrument requires the property of linearity. Linearity is the ability to reproduce the input characteristics symmetrically and linearity.

8. **Error:-** It is the deviation of the true value from the desired value. Also, Error (e) is the difference between the measured value and the true value of a variable.

   error = measured value - true value

9. **Dead zone:-** In some instruments, it is possible that till input increases beyond certain value, the output does not change. So for certain range of input there is no change in output. This range of input is called dead zone.

Dynamic Characteristics

1. **Speed of Response:-** The speed at which the instrument responds whenever there is any change in the quantity to be measured is called **speed of response**. It indicates how fast the instrument is.

2. **Lag:-** The amount of delay present in the response of an instrument whenever there is a change in the quantity to be measured is called measuring lag. It is also simply called **lag**.

3. **Dynamic Error:-** The difference between the true value of the quantity that varies with respect to time and the indicated value of an instrument, is known as dynamic error.

4. **Fidelity:-** The degree to which an instrument indicates changes in the measured quantity without any dynamic error is known as **Fidelity** (faithful reproduction)

Errors in measurement

Static Error:- The algebraic difference between the true value and the measured value is called error, is known as dynamic error. The most important characteristic of an instrument is its accuracy generally expressed in terms of error

$$\text{Error} \quad (\delta_A) = A_m - A_t$$

where δ_A *is the error,* A_m *is the measured quantity and* A_t *is the true value.*

Relative static error = absolute error/ true value

$$\% \, \varepsilon_r = \frac{A_m - A_t}{A_t} \times 100$$

$$\frac{A_m - A_t}{A_t} = \varepsilon_r$$

$$A_m - A_t = A_t \varepsilon_r$$

$$A_m = A_t (1 + \varepsilon_r)$$

or

$$A_t = \frac{A_m}{1 + \varepsilon_r}$$

Errors in measurement

Limiting Error:-The limited deviation of the measured value from the true value is known as the limiting error or guarantee error. **Such type of error is fixed on the instrument**

The actual value of the instrument along with the limiting error is expressed as

$$A_a = A_s \pm \delta A \quad \text{.....} \quad (1)$$

Where,

A_a – actual value

A_s – specified or rated value

δ_A – limiting error or tolerance

Errors in measurement

Relative Limiting Error or Fractional Error:-The relative limiting error is defined as the ratio of the limiting error to the nominal value of the me

$$\varepsilon_r = \frac{\delta A}{A_s} = \frac{\varepsilon_o}{A_s} = \frac{A_a - A_s}{A_s}$$

$$\varepsilon_o = \delta A = \varepsilon_r \cdot A_s$$

From above equations the limiting values are,

$$A_a = A_s \pm \delta A = A_s \pm \varepsilon_r A_s = A_s (1 \pm \varepsilon_r)$$

The relative limiting error, expressed as

$$\varepsilon_r = \frac{A_a - A_s}{A_s}$$

$$\text{Relative Limiting error} = \frac{\text{actual value} - \text{nominal value}}{\text{nominal value}}$$

Numerical Example

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Example-1 :-Three resistors are specified as : R1= 200Ω ± 5%, R2= 100Ω ± 5% and R3= 50Ω ± 5%. Determine the magnitude of the resultant resistance and the limiting error in percentage and in ohms if the resistances are connected in series.

±10Ω ±5Ω ±2·5Ω

Sol.

Step 1: Calculate Resultant Resistance

For series connection,

$$R = R_1 + R_2 + R_3$$

$$R = 200 + 100 + 50 = 350\Omega$$

Resultant Resistance = 350 Ω

Step 2: Calculate Absolute Errors

$$\Delta R_1 = \frac{5}{100} \times 200 = 10\Omega$$

$$\Delta R_2 = \frac{5}{100} \times 100 = 5\Omega$$

$$\Delta R_3 = \frac{5}{100} \times 50 = 2.5\Omega$$

For series connection, limiting errors add directly:

$$\Delta R = \Delta R_1 + \Delta R_2 + \Delta R_3$$

$$\Delta R = 10 + 5 + 2.5 = 17.5\Omega$$

Limiting Error = ±17.5 Ω

Step 3: Calculate Percentage Limiting Error

$$\% \, Error = \frac{\Delta R}{R} \times 100$$

$$= \frac{17.5}{350} \times 100$$

$$= 5\%$$

Hence, the resultant resistance is:

$$\boxed{350\Omega \pm 17.5\Omega}$$

or

$$\boxed{350\Omega \pm 5\%}$$

Example-2: **A 0-150 V voltmeter has a limiting error of 1% of full scale reading. The voltage measured by the instrument is 75 V. Calculate the limiting error in percentage.**

Sol.- Given:

- Voltmeter Range = $0 - 150\ V$
- Limiting error = 1%of full-scale reading
- Measured voltage = $75\ V$

Step 1: Calculate Absolute Limiting Error

$$\Delta V = \frac{1}{100} \times 150 = 1.5\ V$$

So, the limiting error is:

$$\pm 1.5\ V$$

Step 2: Calculate Percentage Limiting Error at 75 V

$$\%\ Limiting\ Error = \frac{1.5}{75} \times 100$$

$$= 2\%$$

Answer:

$$\boxed{\text{Limiting } Error = \pm 2\%}$$

(or $\boxed{\pm 1.5\ V}$ in absolute terms).

Errors in measurement

Classification of Error

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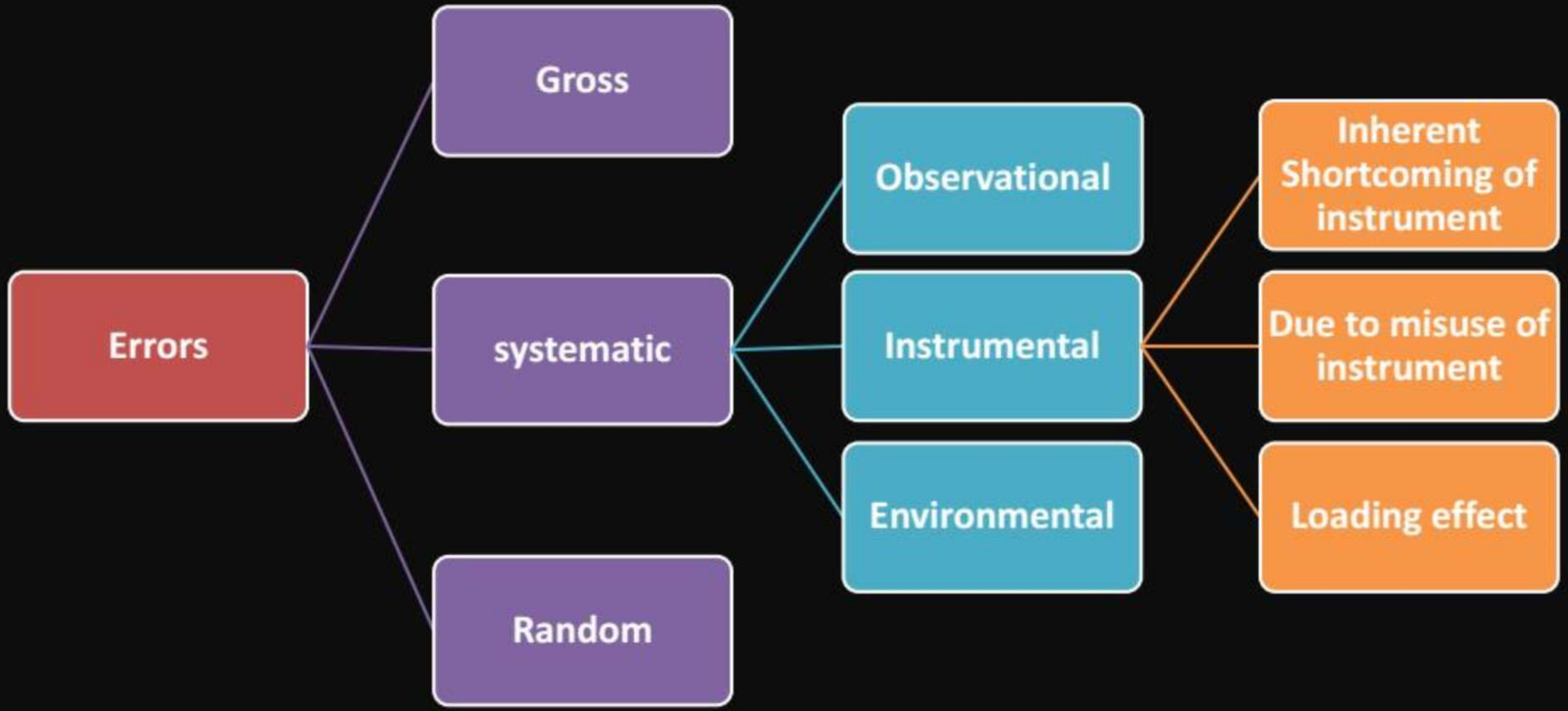

Types of Errors

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Gross Errors:- The gross error occurs because of the human mistakes. For examples consider the person using the instruments takes the wrong reading, or they can record the incorrect data. Such type of error comes under the gross error.

Two methods can remove the gross error. These methods are

- The reading should be taken very carefully.
- Two or more readings should be taken of the measurement quantity. The readings are taken by the different experimenter and at a different point for removing the error.

Random Errors:- The errors, which occur due to unknown sources during measurement time are known as **random errors**. Hence, it is not possible to eliminate or minimize these errors.

Types of Systematic Errors

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Systematic Errors :-

- **Environmental Errors** – This type of errors occur due to the changes in environment such as change in temperature, pressure, dust, humidity vibrations etc.

- **observational Errors** – This type of errors occur due to observer while taking the meter readings. **Parallax errors** belong to this type of errors.

- **Instrumental Errors** – This type of errors occur due to shortcomings of instruments and loading effects.
  - **Inherent Shortcoming of instrument**
  - **Due to misuse of instrument**
  - **Loading effect**

Types of Systematic(Instrumental) Errors

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Inherent Shortcoming of instrument:- Such types of errors are inbuilt in instruments because of their mechanical structure. They may be due to manufacturing, calibration or operation of the device. These errors may cause the error to read too low or too high.

Due to misuse of instrument:- The error occurs in the instrument because of the fault of the operator. A good instrument used in an unintelligent way may give an enormous result.

Loading effect:- The most frequent type of this error will occur due to the measurement work in the device. For instance, as the voltmeter is associated to the high-resistance circuit may give a false reading, but when it is allied to the low-resistance circuit, this circuit will give the reliable reading, and then the example shows that the voltmeter has the effect of loading.

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Standards of Measurement

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Different Types of Standards of Measurement are classified in categories

- **International Standards,**
- **Primary Standards,**
- **Secondary Standards, and**
- **Working Standards.**

International Standards:- International standards are defined by International agreement. They are periodically evaluated and checked by absolute measurements in terms of fundamental units of Physics. They represent certain units of measurement to the closest possible accuracy attainable by the science and technology of measurement. These International Standards of Measurement are not available to ordinary users for measurements and calibrations.

Ex. **International ohms:** It is defined as the resistance offered by a column of mercury having a mass of 14.4521 gms, uniform cross-sectional area and length of 106.300 cm, to the flow of constant current at the melting point of ice.

1 International ohm = 1.00049 Absolute ohm

Standards of Measurement

GW GATEWAY CLASSES

- **Primary Standards:** The principle function of primary standards is the calibration and verification of secondary standards. Primary standards are maintained at the National Standards Laboratories in different countries.

- **Secondary Standards:** Secondary standards are basic reference standards used by measurement and calibration laboratories in industries. These secondary standards are maintained by the particular industry to which they belong. Each industry has its own secondary standard. Each laboratory periodically sends its secondary standard to the National standards laboratory for calibration and comparison against the primary standard.

- **Working Standards:** Working standards are the principal tools of a measurement laboratory. These standards are used to check and calibrate laboratory instrument for accuracy and performance. For example, manufacturers of electronic components such as capacitors, resistors, etc. use a standard called a working Standards of Measurement for checking the component values being manufactured.

Essentials of Indicating Instruments

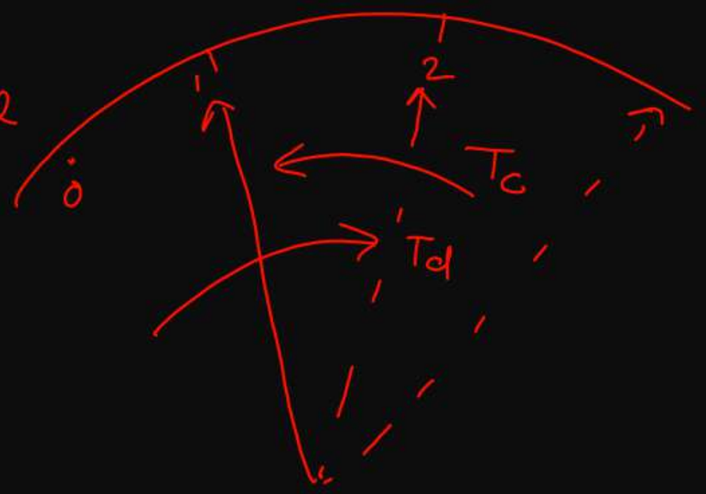
There are three **Essentials of Indicating Instruments**. These are as follows:

1. Deflecting Torque

2. Controlling Torque

Controlling torque

Deflection Torque



(i) **Spring Control**

(ii) **Gravity Control**

3.Damping Torque

(i) **Air friction Damping**

(ii) **Fluid Friction Damping**

(iii) **Eddy Current Damping**

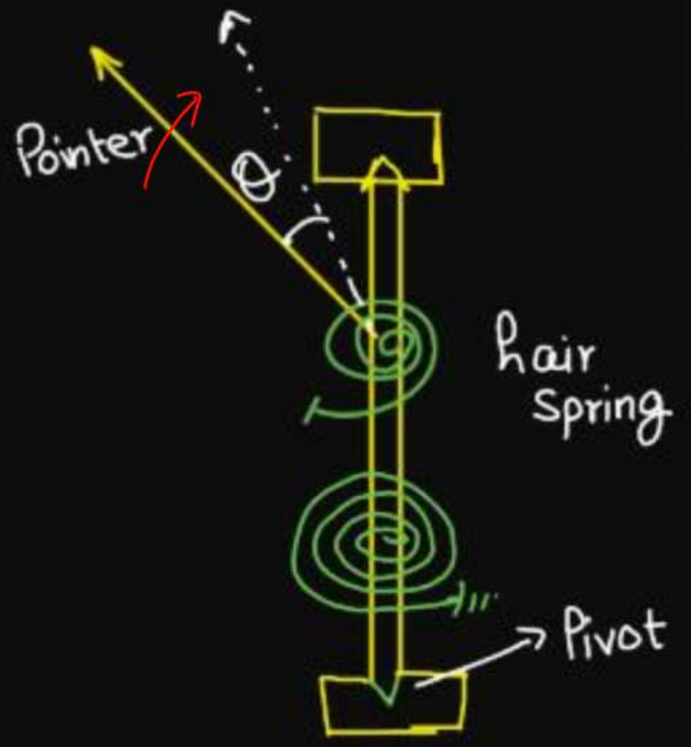
Deflecting Torque

1. Deflecting Torque:- Deflecting torque causes the moving system and pointer of the instrument to move from its zero position. The deflecting torque is produced by utilizing one or more of the following effects of current or voltage:

S.No.	Type	Effect	Suitable for	Instrument
1.	Moving-iron	Magnetic effect	d.c and a.c.	Ammeters Voltmeters
2.	Moving coil	Electrodynamic effect	d.c. only	Ammeters Voltmeters
3.	Dynamometer type	Electrodynamic effect	d.c and a.c.	Ammeters Voltmeters Watt-meters. Usually for watt-merers.
4.	Induction type	Electromagnetic induction effect	a.c. only	Ammeters Voltmeters Watt-meters Energy meters. Usually for watt-merers and energy meters.

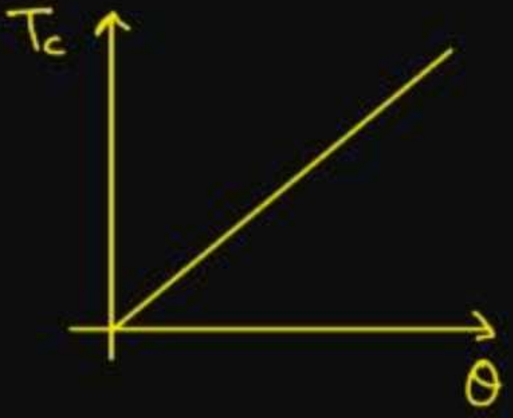
Controlling Torque

Controlling Torque:- The controlling force is always acts in opposite direction to the deflecting force. And also return the pointer to its initial zero position when the instrument is disconnected from the supply. The controlling force could be produced by



(i) Spring Control:-The most common arrangement of two spring control utilizes. Which is made up of phosphor-bronze or beryllium copper spiral hair-springs A and B, the inner ends of which are attached to the spindle. $T_c \propto \theta$, $T_c = K_s.\theta$

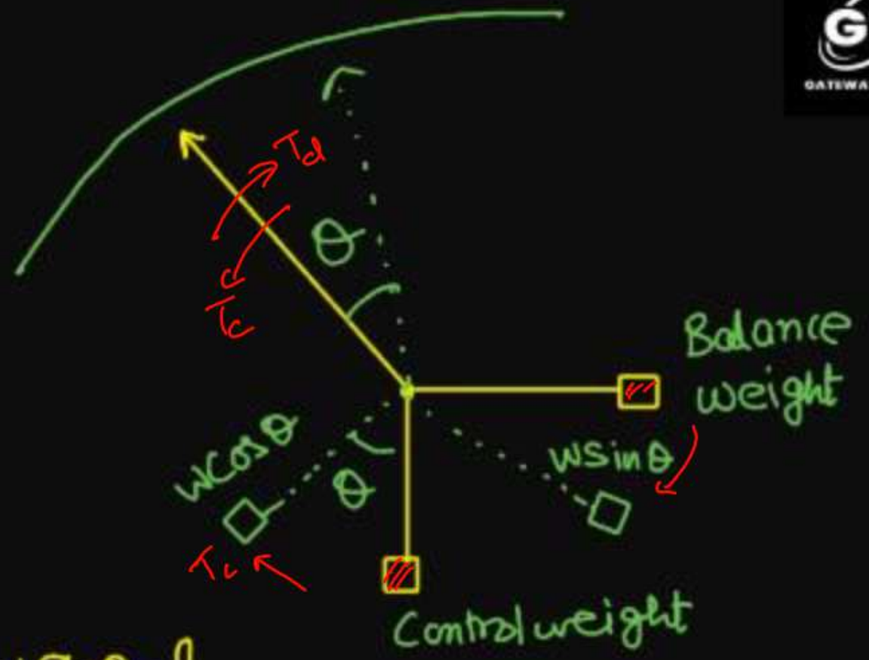
Both springs A and B are wound in opposite directions so that when pointer is deflecting, one spring winds up while the other unwinds. Therefore the controlling force is produce due to the combined torsions of the springs.



Controlling Torque

(i) Gravity Control:-In this method, small adjustable weights are attached to the opposite extension of the pointer.

- When the instrument is disconnected from the supply, the control weight and the balance weight attached to the opposite end of the pointer make the pointer to be at zero position.
- When the instrument is connected to the supply, the pointer moves in a clockwise direction, thereby displacing the weights shown in figure.
- Due to the gravitational pull, the weights will try to come back to its original position.



$T_c \propto W \sin\theta \cdot l$

$T_c = K W l \sin\theta$

$T_c = K' \sin\theta$

for operation

$T_c = T_d$

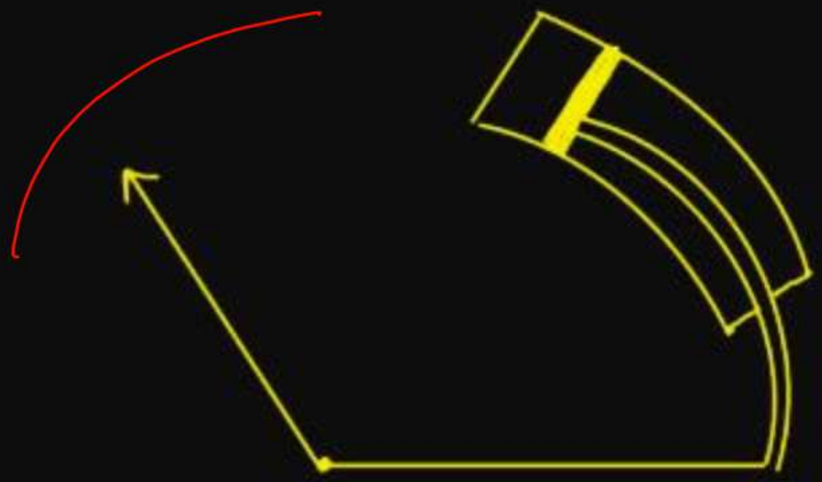
$K \sin\theta = K_i l$

$T_d \propto I \quad , T_d = K_d . I$

$\boxed{I \propto \sin\theta}$

Damping Torque

3. Damping Torque:-The combined inertia Tc and Td allows the moving system to settle quickly at final position. The pointer oscillates about the final steady position before it comes to rest. Thus, damping torque is required to damp out the oscillations and enable the pointer to reach to its final position.

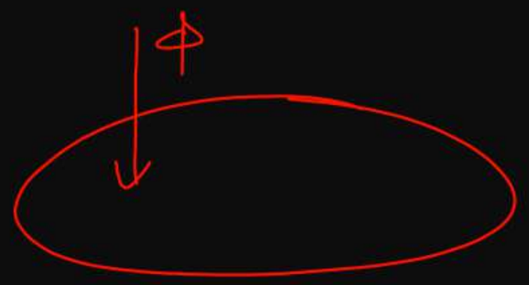


(i) Air friction Damping:-A light aluminum piston is attached to the moving system. If the piston is moved into the chamber, the air inside the chamber is compressed and pressure opposes the motion of the piston.

(ii) Fluid Friction Damping:- Fluid-friction is similar in action to the air friction. Due to greater viscosity of oil, the damping is more effective. However, oil damping is not much used because of several disadvantages such as objectionable creeping of oil.

Damping Torque

(iii) Eddy Current Damping:-Damping torque in measuring instruments can be produced based on the concept of eddy current flowing in a closed path in which emf is induced based on the principle of electromagnetic indication. A thin disc D of aluminum is mounted on spindle P and moves b/w the magnet. and produces emf. in the disc. The emf induced causes eddy currents which produce damping torque

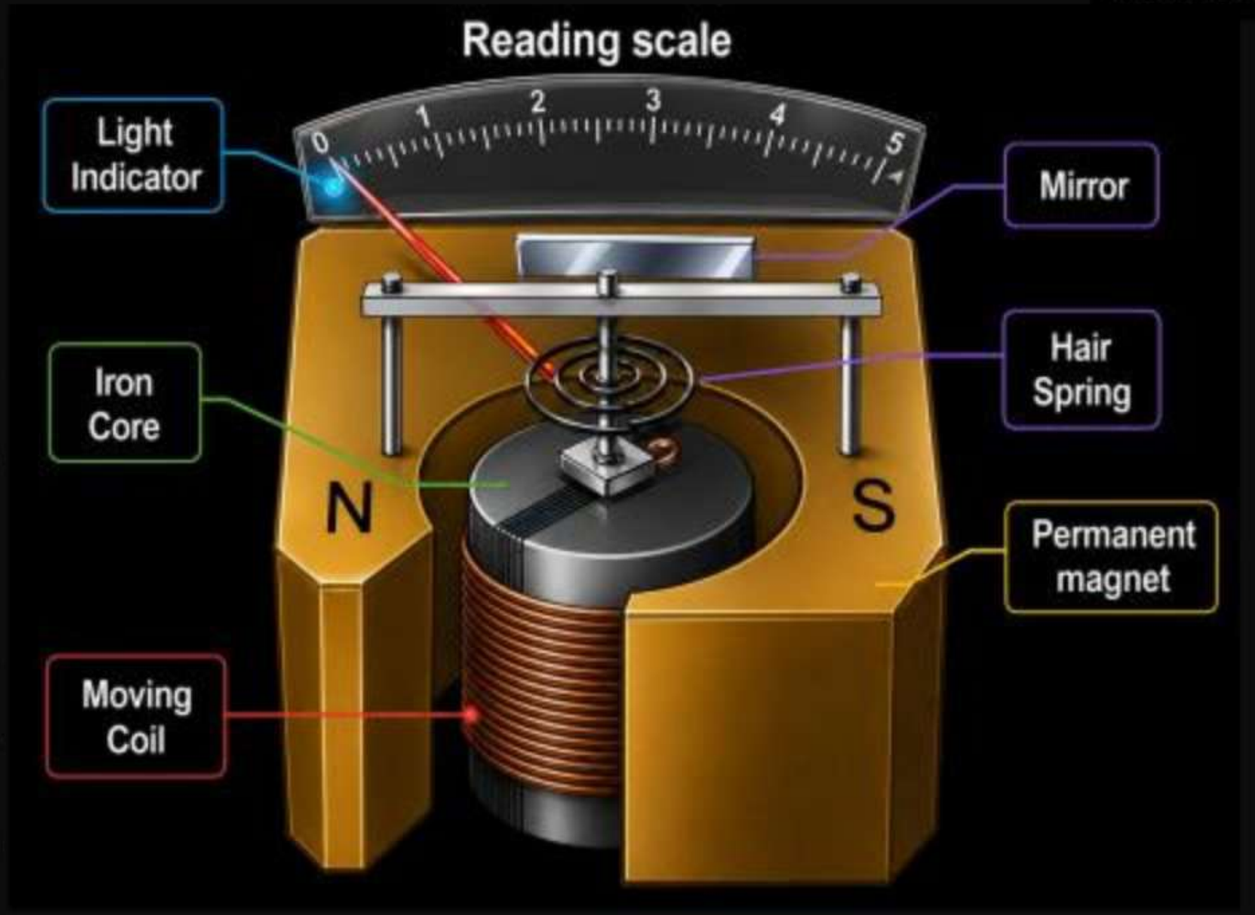


Permanent Magnet Moving Coil Instrument (PMMC)

Imp

These instruments use permanent magnets to create the stationary magnetic field in the coils.

- Whenever a current caring conductor is located within a magnetic field, then it experiences a force that is perpendicular to the current & the field.
- After that the magnetic field will be in the forefinger, the flow of current will be across the middle finger and finally, the force will be through the thumb finger. Once the current flow within the coil on the aluminum former, the magnetic field can be generated in the coil in proportion to the current flow.



Construction of Permanent Magnet Moving Coil Instrument

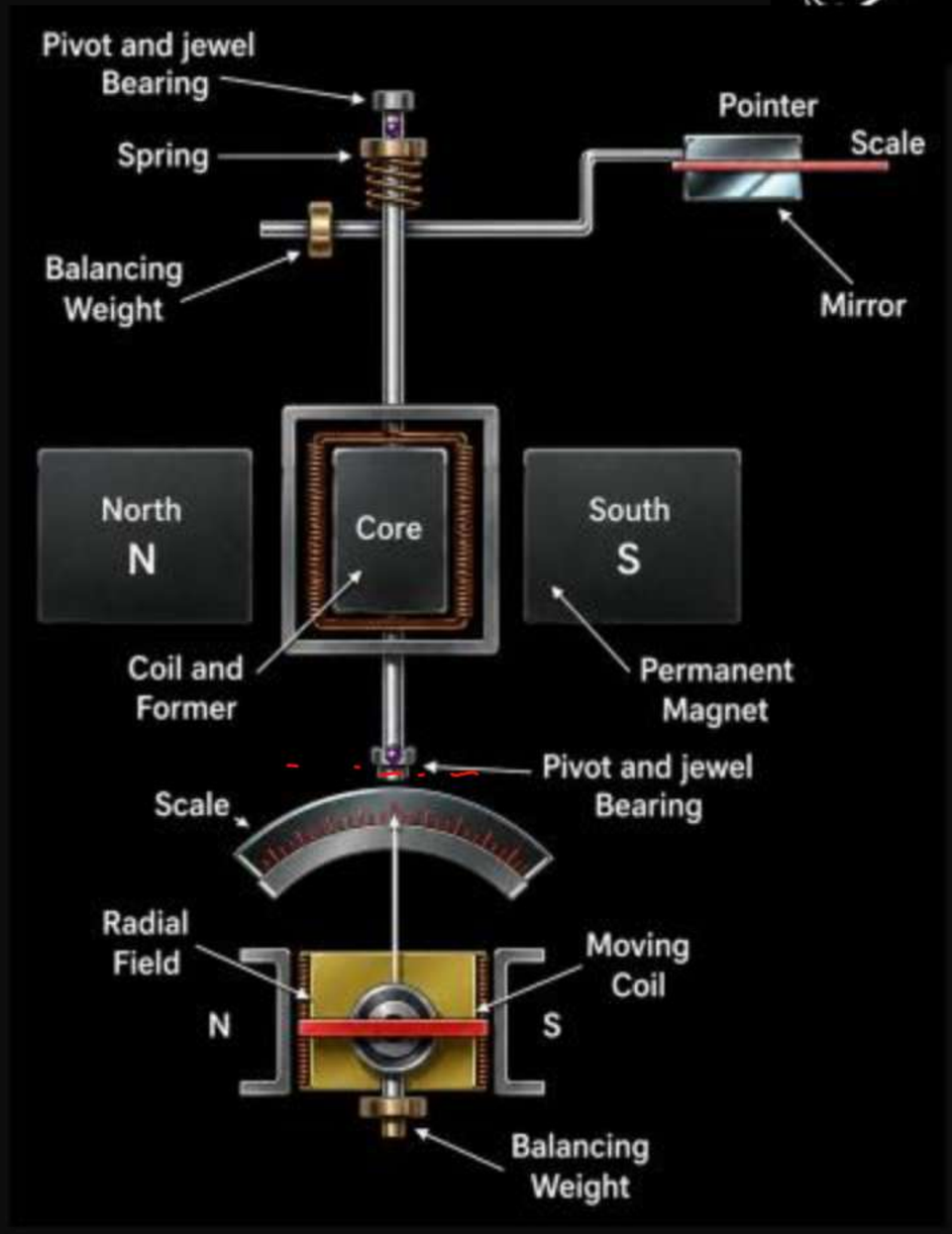
Moving Coil:- Coil Wound with many turns of fine, insulated copper wire. The coil is wound around a lightweight, non-magnetic aluminum or copper former. It is mounted on a spindle that rests on jewel bearings to minimize friction

Magnet system: A strong, horseshoe-shaped permanent magnet made of materials with high coercivity and retentivity (like Alnico or Alcomax) to ensure a constant, strong magnetic field.

Control spring: Two phosphor-bronze hairsprings are used to provide the controlling torque. They are wound in opposite directions to neutralize temperature effects.

Damper: Damping is provided by the movement of the metallic (aluminum) former in the permanent magnetic field.

Pointer and Scale arrangement: Pointer is Attached to the moving coil spindle, moves on a scale to provide reading.



Torque Equation of PMMC

Deflection Torque :-

$$T_d = F \times d$$
$$= N \cdot B i l \cdot d$$
$$= G \cdot I$$

where $G = NBl \cdot d$

Controlling Torque

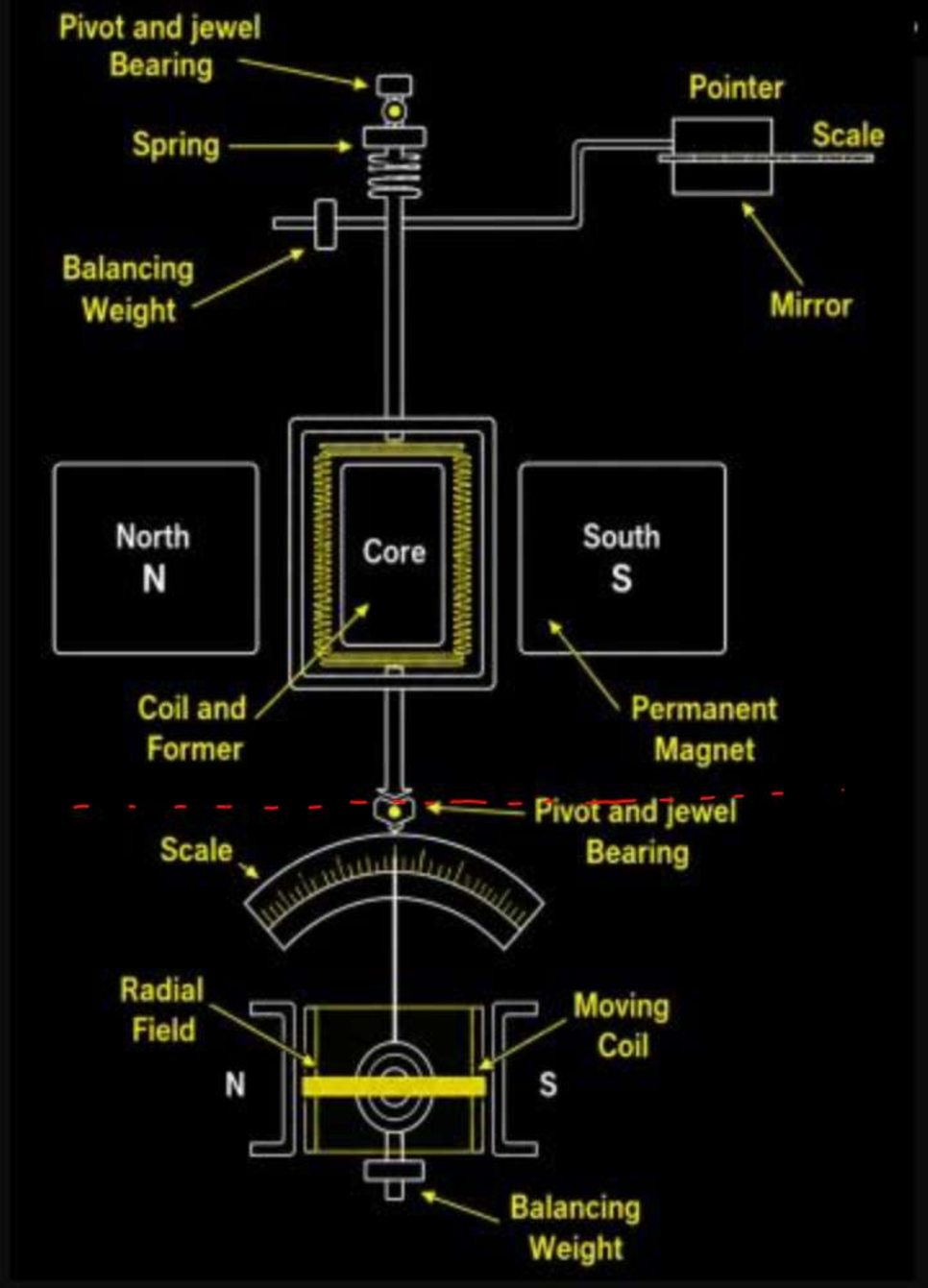
$$T_c = K\theta$$

For steady operation

$$T_c = T_d$$
$$G \cdot I = K\theta$$
$$I = \left(\frac{K}{G}\right)\theta$$

$$\boxed{I \propto \theta}$$

Scale will be uniform.



Advantages & Disadvantages of PMMC

Advantages:- (Only for D.C)

- The scale is uniformly divided as the current is directly proportional to deflection of the pointer.
- The power consumption of the devices is very less.
- The PMMC instruments have high accuracy because of the high torque weight ratio.
- The single device measures the different range of voltage and current. This can be done by the use of multipliers and shunts.

Disadvantages:-

- These instruments cannot measure AC quantities.
- The cost of these instruments is high as compared to moving iron instruments.
- It shows an error because of the magnetism loss in the permanent magnet.

Application:-

It is used as an Ammeter , Voltmeter, Ohm meter or as a Galvanometer.

Moving Iron Instrument

The instrument in which the moving iron is used for measuring the flow of current or voltage is known as the moving iron instrument. It works on the principle that the iron place near the magnet attracts towards it. The force of attraction depends on the strength of the magnet field. The magnetic field induces by the electromagnet whose strength depends on the magnitude of the current passes through it.

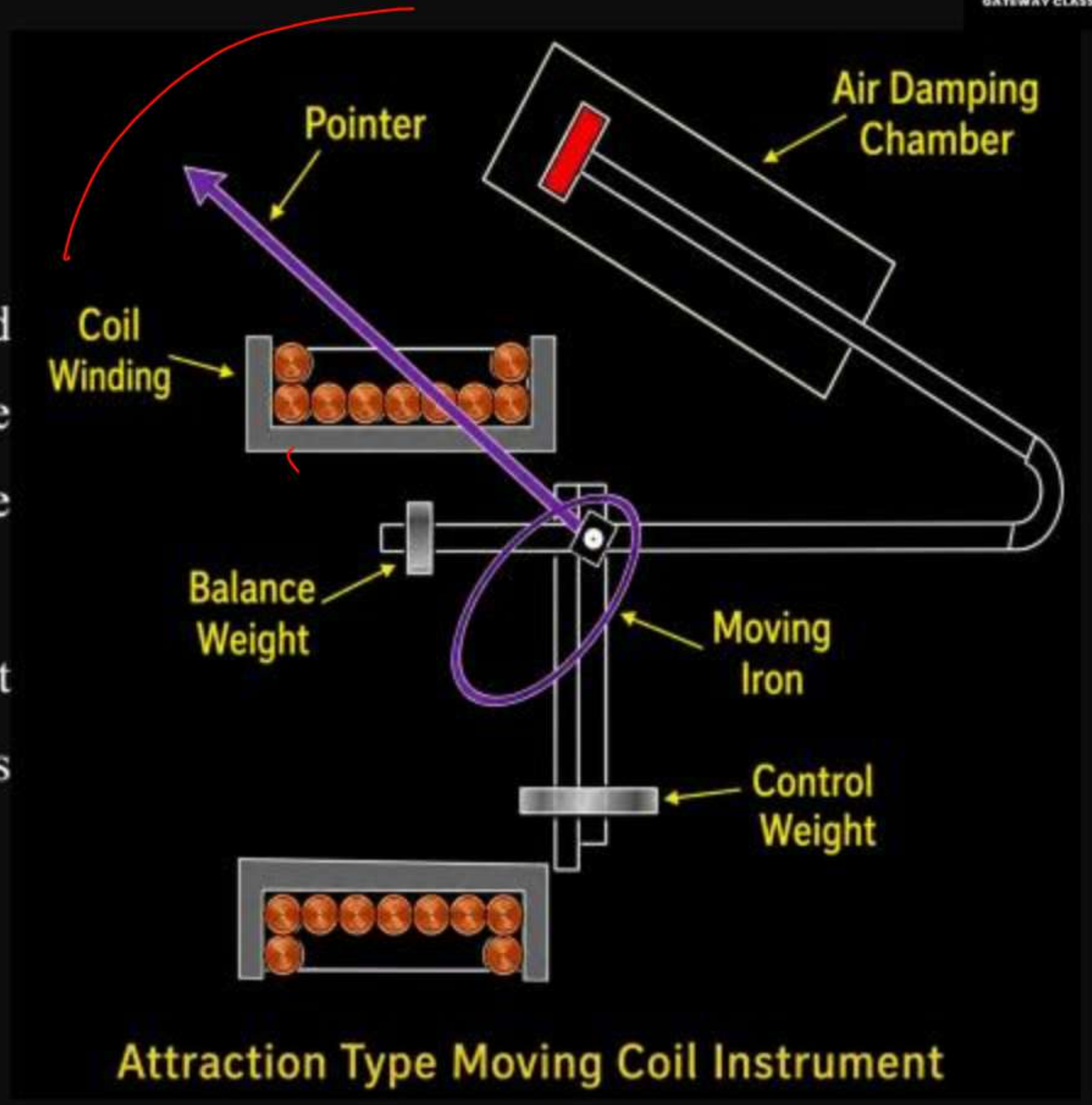
There are mainly two categories of moving iron instruments.

- **Attraction Type**
- **Repulsion Type**.

Moving Iron Instrument (Attraction Type)

Attraction Type:-

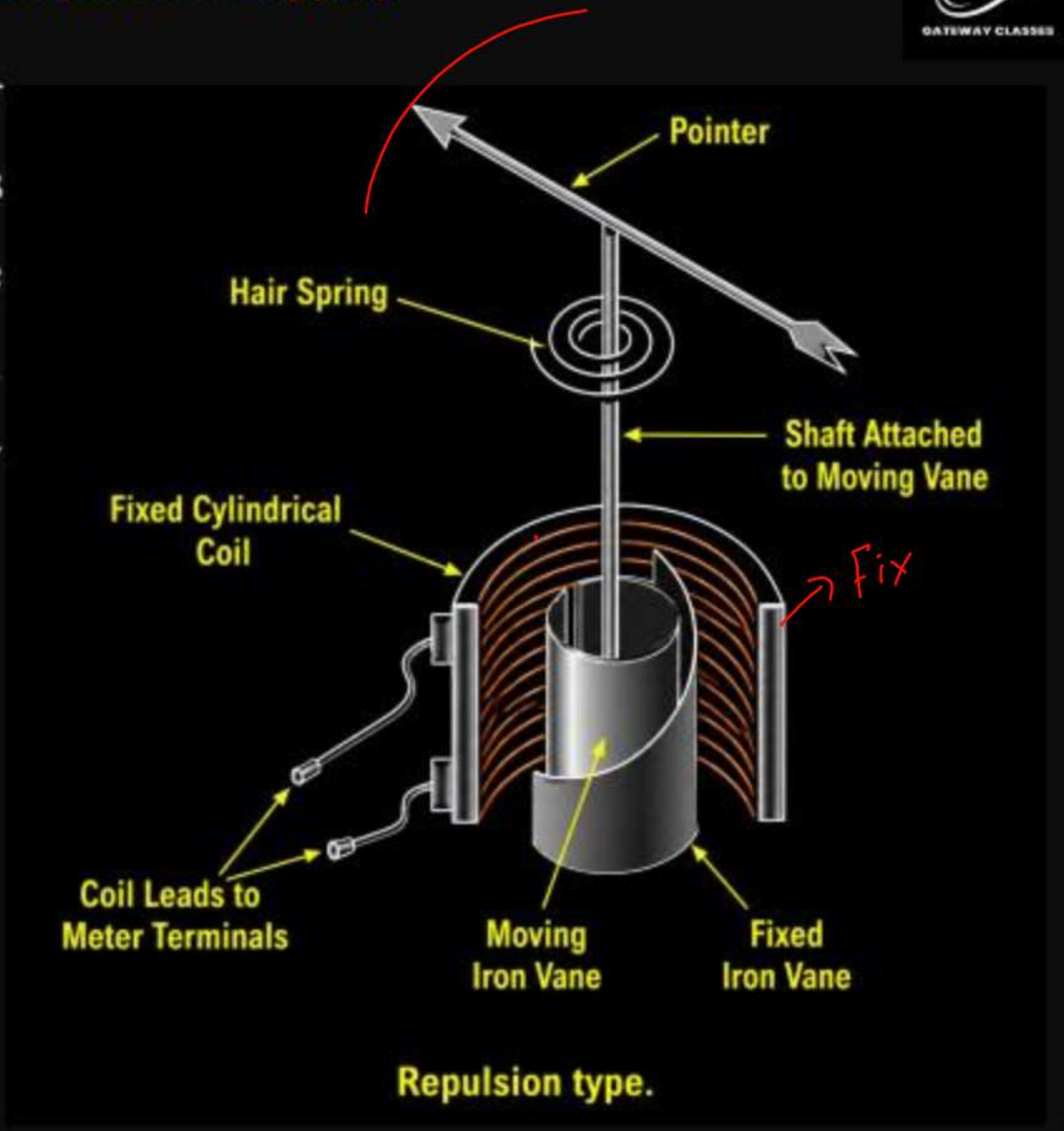
- The coil is flat and has a narrow slot like opening.
- The moving iron is a flat disc
- Then the current flows through the coil, a magnetic field is produced and the moving iron moves from the weaker field outside the coil to the stronger field inside it or in other words the moving iron is attracted in.
- The controlling torque is providing by springs but gravity control can be used for panel type of instruments which are vertically mounted.
- Damping is provided by air friction



Attraction Type Moving Coil Instrument

Moving Iron Instrument (Repulsion Type)

Repulsion Type. The repulsion type instrument has two vanes or iron plates. One is fixed, and the other one is movable. The vanes become magnetized when the current passes through the stationary coil and the force of repulsion occur between them. Because of a repulsive force, the moving coil starts moving away from the fixed vane.



Repulsion type.

Moving Iron Instrument

Derivation of Deflecting Torque

Let:

- I= current through the coil
- L= inductance of the coil (depends on iron position)
- θ= deflection angle

Step 1: Energy stored in the magnetic field

For a coil: $W = \frac{1}{2}LI^2$

Step 2: Change in energy with deflection

When the iron moves by a small angle $d\theta$, inductance changes by dL.

Change in stored energy:

$$dW = \frac{1}{2}I^2\,dL$$

Step 3: Mechanical work done

Mechanical work done:

$$dW = T_d\,d\theta$$

Where T_d is the **deflecting torque**.

Step 4: Equating energies

$$T_d\,d\theta = \frac{1}{2}I^2\,dL$$

$\boxed{T_d = \frac{1}{2}I^2\frac{dL}{d\theta}}$ **6. Final Expression for Deflecting Torque**

$$\boxed{T_d \propto I^2}$$

Moving Iron Instrument (Repulsion Type)

GW
GATEWAY CLASSES

Advantages

- This instrument is applicable for both AC & DC.
- This device has very less friction error due to a high torque weight ratio
- These instruments are available at less cost
- This is robust due to its very simple construction.
- It can resist overload for a moment.

Disadvantages:-

- The scale is not uniform.
- The errors in this instrument can be caused because of the hysteresis within the iron & stray magnetic field.
- Change within frequency can cause very serious errors in AC measurements.
- This instrument is non directional, so its accuracy is low.

Applications

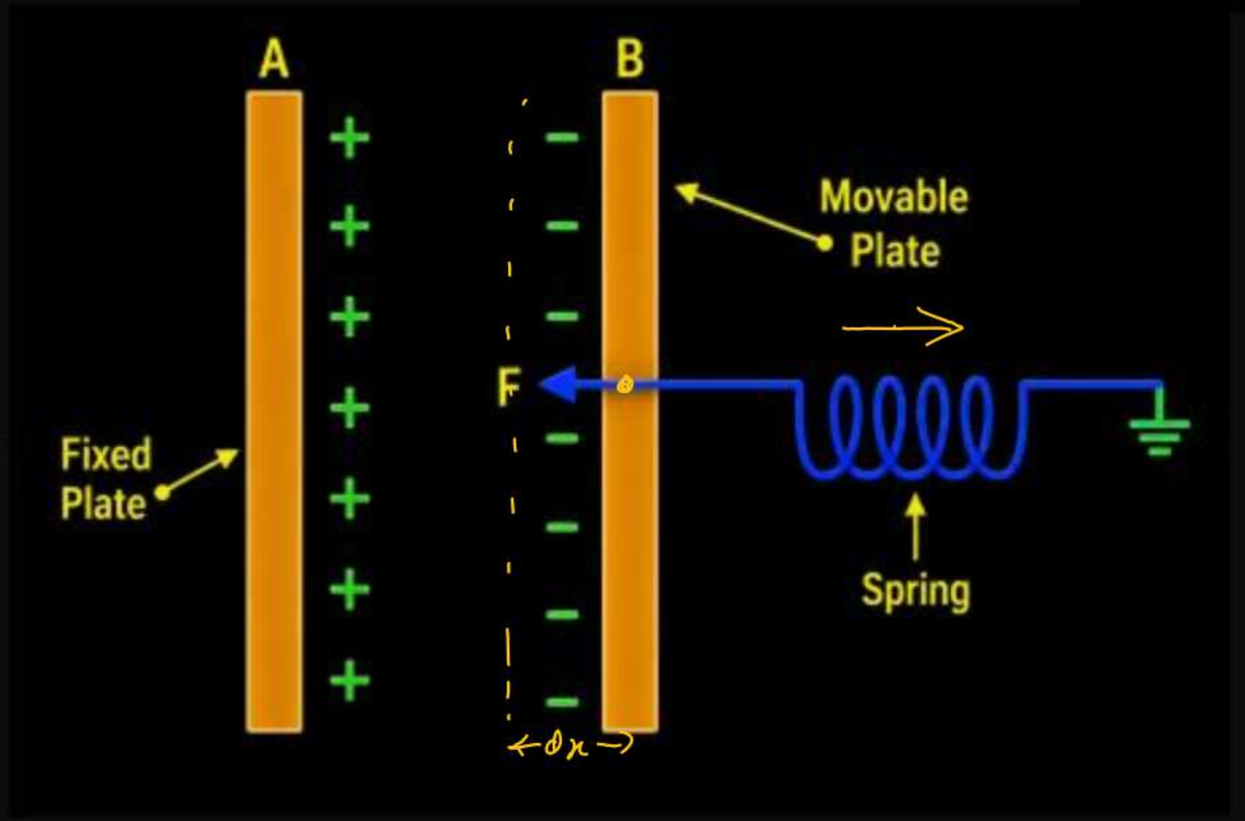
- These instruments are mainly used as an ammeter, voltmeter & wattmeter which can work on both AC & DC.
- These MI instruments are extensively used in switchboards & labs.

Electrostatic Instrument

In these type of instruments deflecting torque is produced by electric field on charged conductor. These are essentially voltmeters.

There are two ways in which force act

Linear Type Electrostatic Instrument:- When one of the plates is fixed and other plate is free to move, plates are oppositely charged in order to have attractive force between them. Now due this attractive force movable plate will move towards the stationary or fixed plate till the moving plate stored maximum electrostatic energy.



Electrostatic Instrument

Equation for deflection force :-

IF Capacitance is C, Energy stored is CV^2

Capacitance is not Constant

Current $i = \frac{dq}{dt} = \frac{d}{dt}CV = \left(V\frac{dc}{dt} + C\frac{dV}{dt}\right)$

Input Energy is given by (P x t)

$$v.i.t = \left(V\frac{dc}{dt} + C\frac{dV}{dt}\right) v\,dt$$

$$= v^2dc + CVdV$$

change in energy $= \frac{1}{2}(C+dc)(V+dV)^2 - \frac{1}{2}CV^2$

$$= \frac{1}{2}v^2dc + CVdV$$

Law of Conservation of Energy

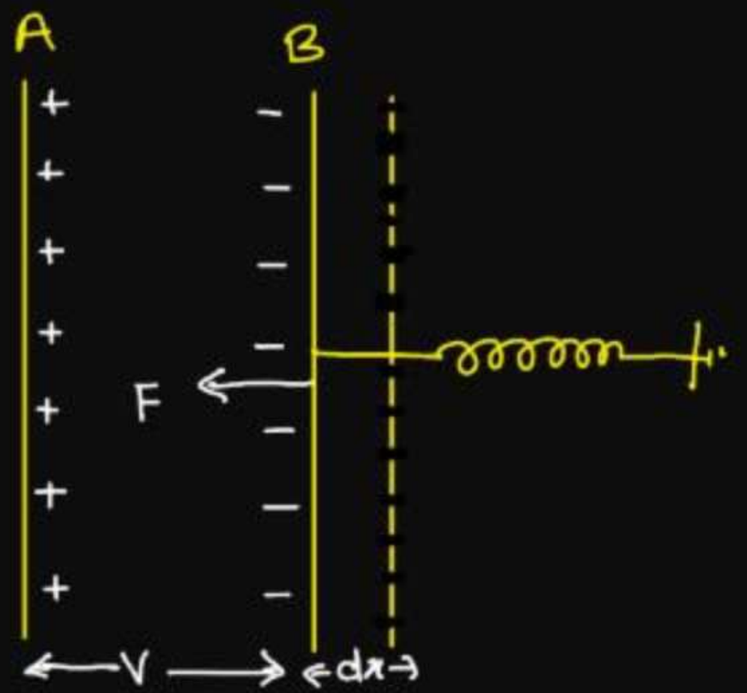
I/p Energy = o/p energy + Δ in energy

$$v^2dc + CV\,dV = f\cdot dx + \frac{1}{2}v^2dc + CV\,dV$$

ΔE

$$Fdx = \frac{1}{2}v^2dc$$

$$\boxed{F = \frac{1}{2}v^2\frac{dc}{dx}}$$



Electrostatic Instrument

Rotary type Electrostatic Instrument:- In other arrangement there may be force of attraction or repulsion or both, due to some rotary of plate.

In Linear movement $F = \frac{1}{2} V^2 \frac{dC}{dx}$

In Angular movement $T_d = \frac{1}{2} V^2 \frac{dC}{d\theta}$

Controlling Torque $T_c = K \cdot \theta$

For steady operation

$$T_d = T_c$$

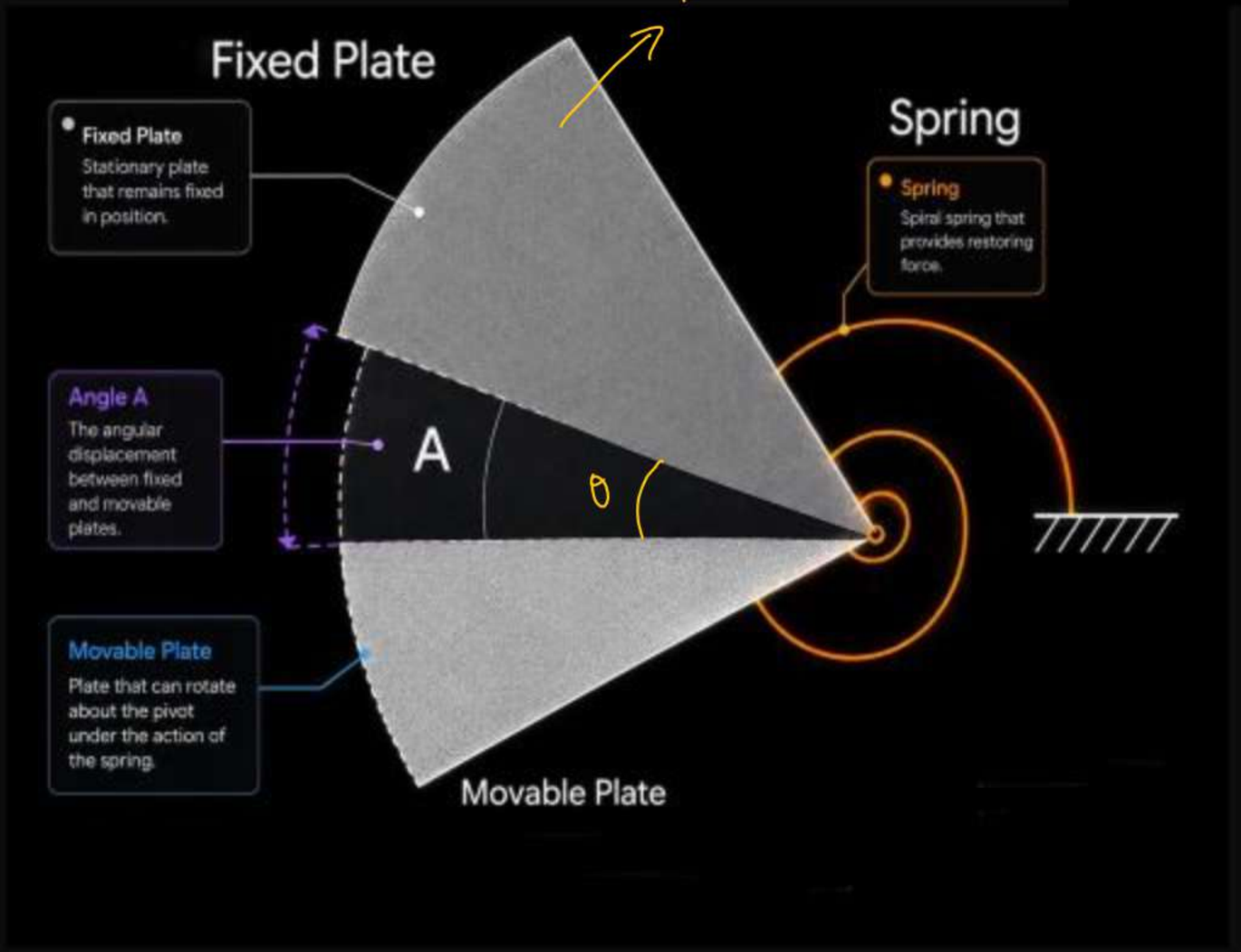
$$K\theta = \frac{1}{2} V^2 \frac{dC}{d\theta}$$

$$\theta = \frac{1}{2K} V^2 \frac{dC}{d\theta}$$

or

$$\theta \propto V^2$$

So Scale is non uniform.



Electrostatic Instrument

Advantages :-.

- we can measure both AC and DC voltage
- Power consumption is quite low in these types of instruments as the current drawn by these instruments is quite low.
- We can measure high value of voltage.

Disadvantages of Electrostatic Type Instruments

- These are quite costly as compared to other instruments and also these have large size.
- The scale is not uniform.
- The various operating forces involved are small in magnitude.

Imp

Induction Type Instrument (Single Phase energy Meter)

AKTU-2025-26

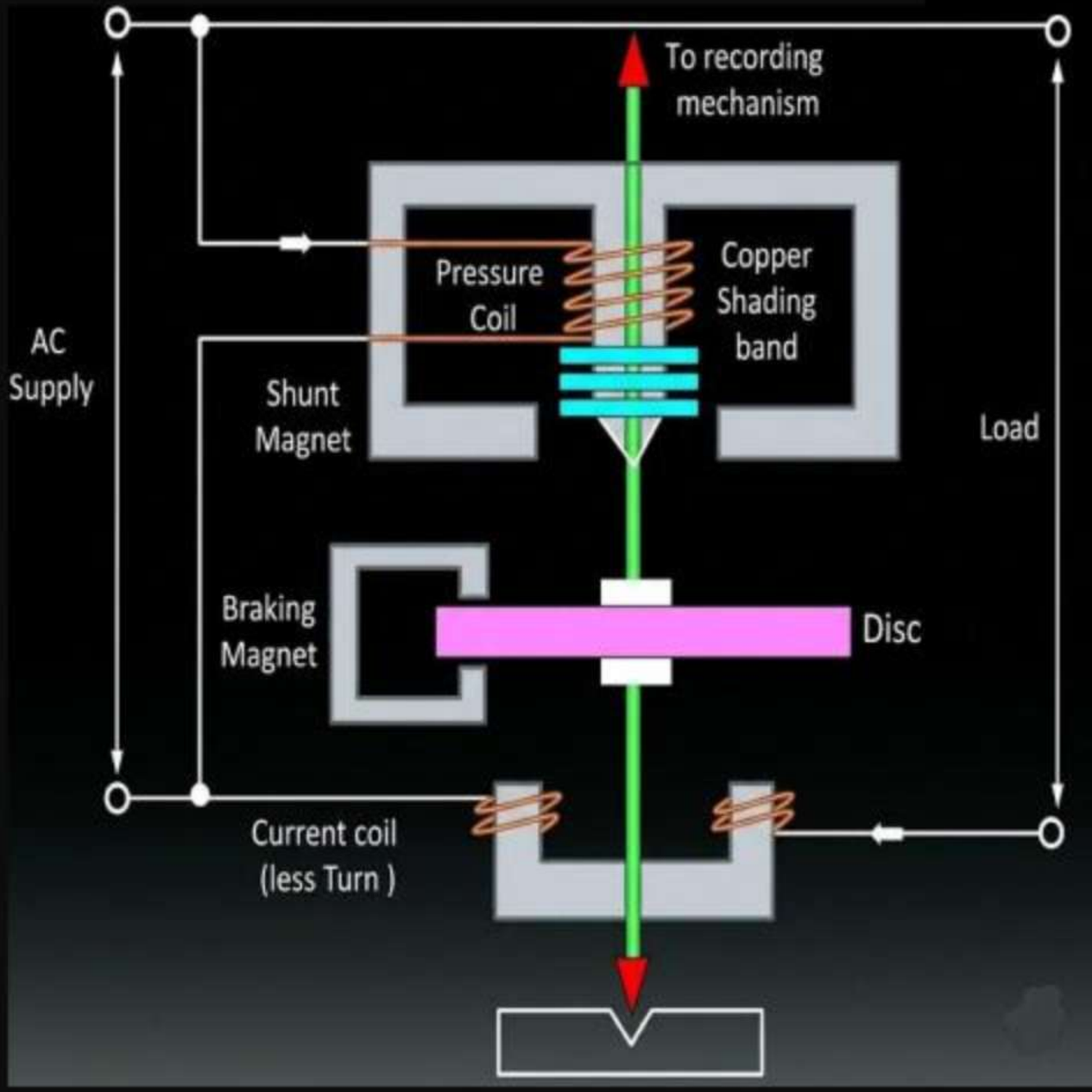
Construction:-

1. Driving System: It produces the torque required to rotate the aluminum disc. Consists of two electromagnets:

Series Magnet (Current Coil): Connected in series with the load and carries load current.

Shunt Magnet (Pressure Coil): Connected across the supply voltage.

Working: The alternating fluxes produced by the two magnets induce eddy currents in the aluminum disc. Interaction between these fluxes and eddy currents produces **driving torque**. The driving torque is proportional to power consumed.



Induction Type Instrument (Single Phase energy Meter)

AKTU-2025-26

2. Moving System The moving system rotates under the action of the driving torque. A lightweight aluminum disc mounted on a spindle. The spindle is supported by bearings to reduce friction.

Working: Eddy currents induced in the disc interact with magnetic fields. As a result, the disc rotates at a speed proportional to the power consumed.

3. Braking System:- The braking system controls the speed of the rotating disc. It Consists of a **permanent magnet** placed near the edge of the aluminum disc.

Working: When the disc rotates through the magnetic field of the permanent magnet, eddy currents are induced in the disc. These eddy currents produce a braking torque that opposes the motion. Braking torque is proportional to the speed of the disc.

4. Registering System: The registering system records the energy consumed. A gear train connected to the spindle. Counting mechanism with dials or digital register.

Working: The rotating disc drives the gear train. The gear train operates the counting mechanism. The reading is displayed in **kilowatt-hours (kWh)**, also called **units of electrical energy**.

Induction Type Instrument

AKTU-2025-26

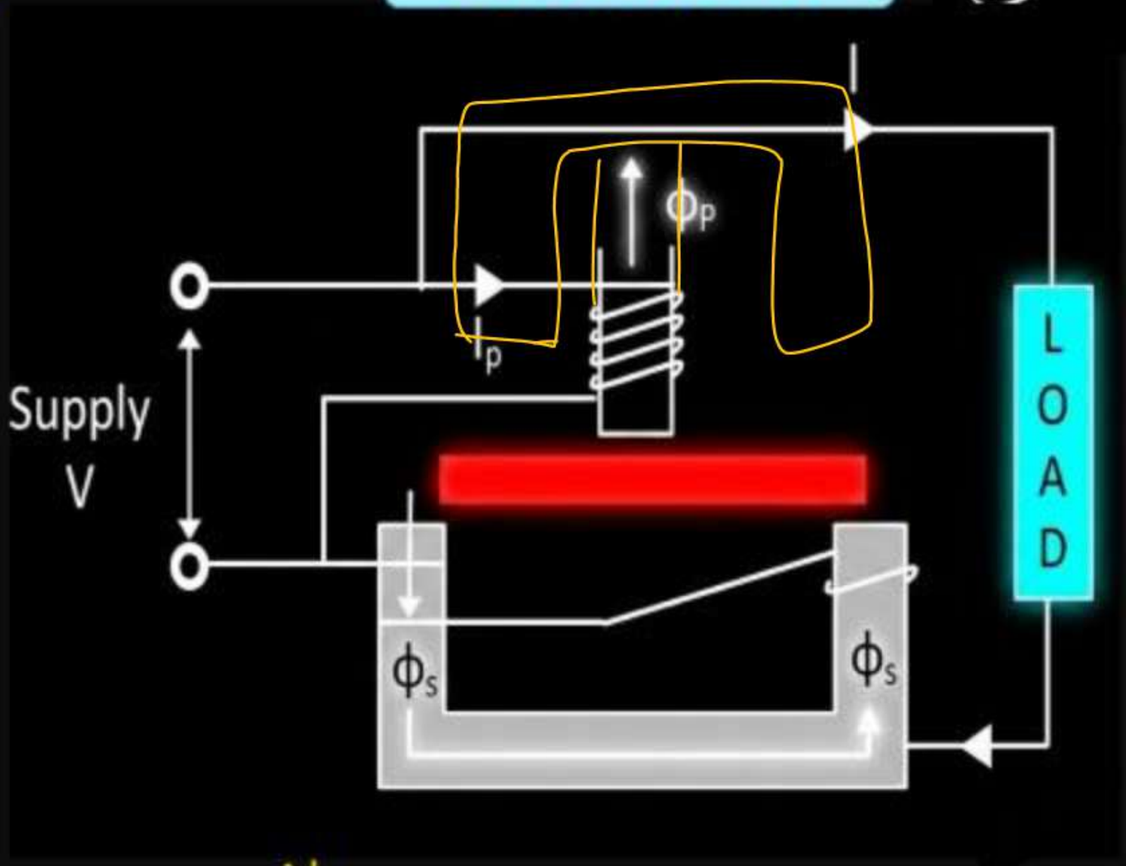
Working: The meter works on the principle of **electromagnetic induction**. The interaction of magnetic fluxes produced by the current coil and pressure coil induces eddy currents in an aluminum disc, producing a driving torque that rotates the disc.

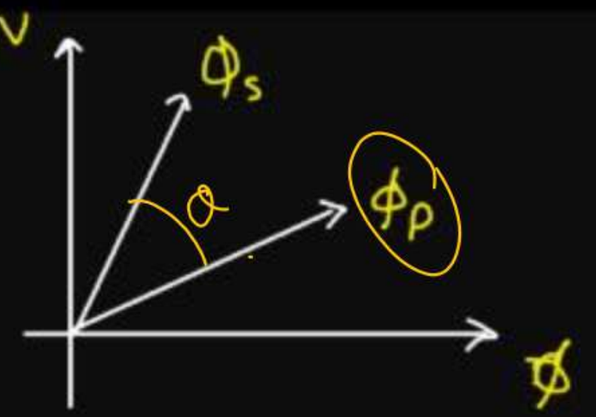
Current I_p Supplies flux ϕ_p

$$\phi_p \propto V$$

ϕ_p is Lagging due to large inductive Coil and produce eddy Current I_{ep} in disc.

Load Current I_s produce flux ϕ_s which is less reactive and highly resistive, produce Current I_{es} in disc





Induction Type Instrument

Working:- Deflection Torque is given by

$$T_d \propto \phi_p \cdot \phi_s \frac{f}{Z} \sin\beta \cos\alpha$$

where f = freq., Z = Impedance of eddy Current Path

β = angle b/w ϕ_p & ϕ_s

$$T_d \propto \phi_p \phi_s \frac{f}{Z} \sin(\Delta - \phi) \cos\alpha$$

As $\phi_p \propto V$ and $\phi_s \propto I$

$$T_d \propto VI \frac{f}{Z} \sin(\Delta - \phi) \cos\alpha$$

if f, Z, α are Constant

$$T_d \propto VI \sin(\Delta - \phi)$$

$$T_d = K_1 VI \sin(\Delta - \phi)$$

Breaking Torque $T_B \propto N$

$$T_B = KN$$

At steady state

$$T_d = T_B$$

$$K_1 VI \sin(\Delta - \phi) = KN$$

if Δ is 90°

$$K_2 VI \cos\phi = N$$

N = Power × K

$N \propto$ Power

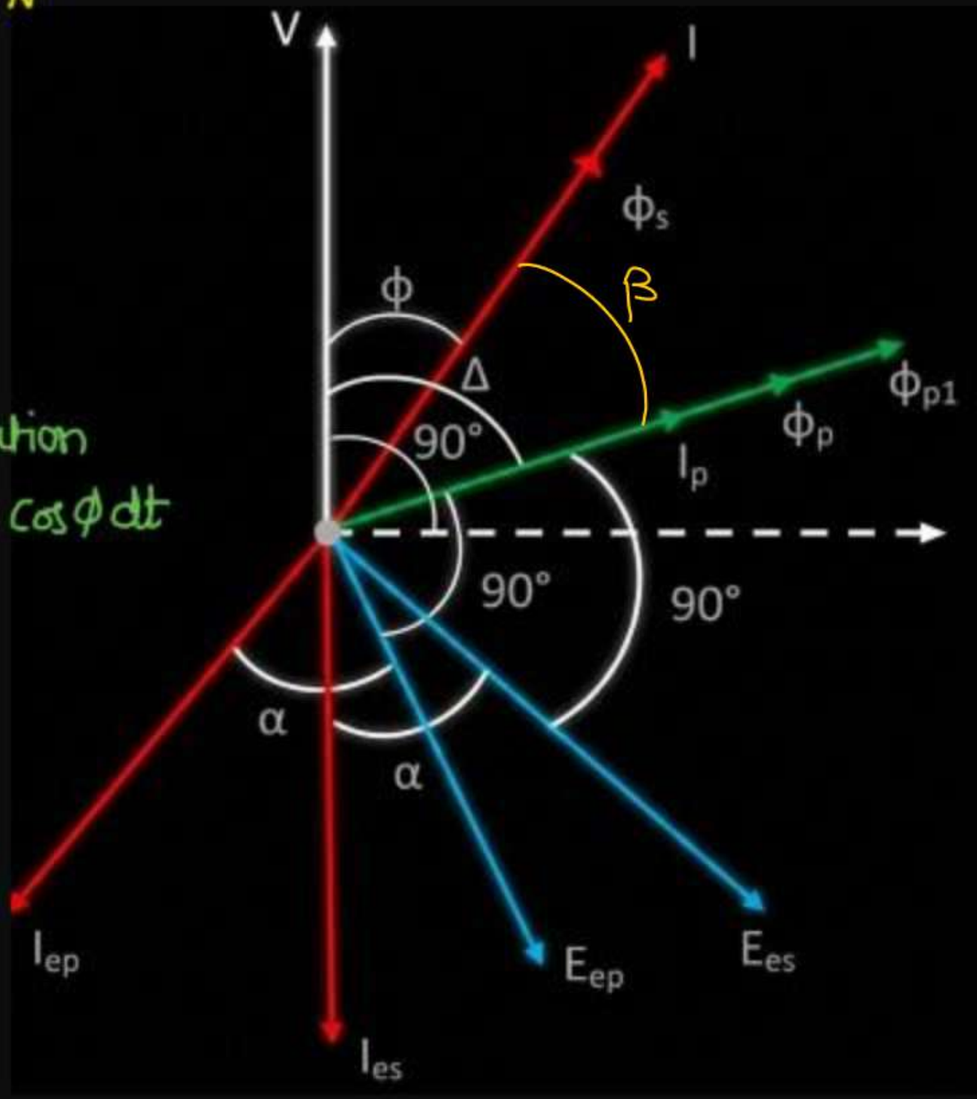
Total No. of revolution

$$N = \int N \cdot dt = \int K_2 VI \cos\phi \, dt$$

$$N = K \int VI \cos\phi \, dt$$

$$N = K \cdot \int P \cdot dt$$

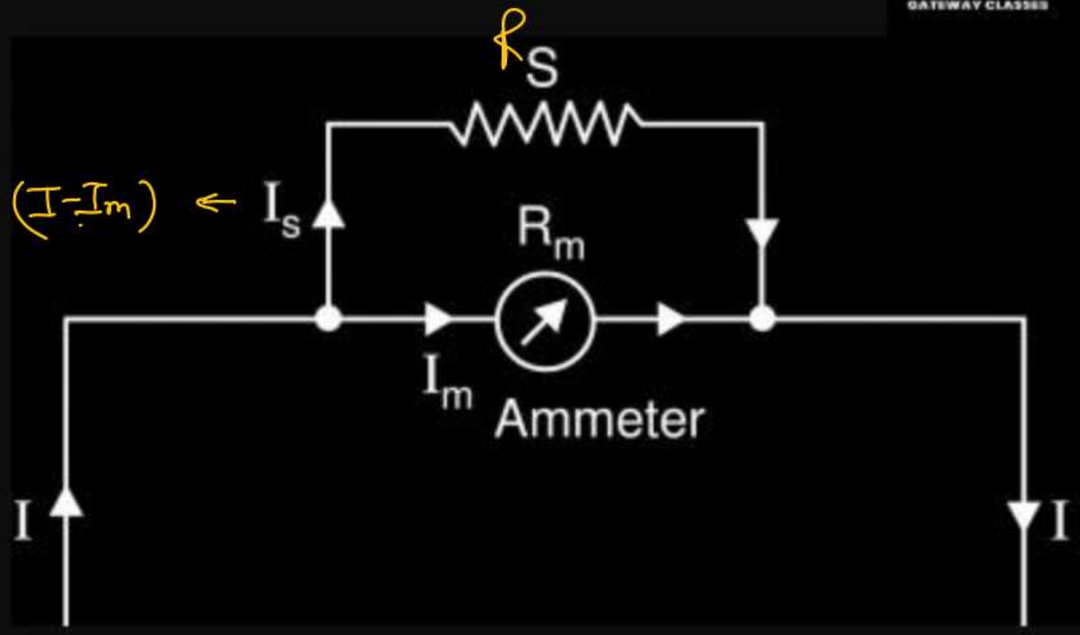
$N \propto$ Energy



Extension of range of PMMC Instruments

PMMC Ammeter

- The range of a PMMC ammeter can be extended by connecting a low resistance, called shunt in parallel with the moving coil of the instrument.
- The shunt bypasses most of the line current and allows a small current through the meter which it can handle without burning.



$$I_m R_m = (I - I_m) R_s$$

$$R_s = \frac{I_m R_m}{I - I_m} = \frac{I_m R_m}{\left(\frac{I}{I_m} - 1\right) I_m} = \frac{R_m}{\left(\frac{I}{I_m} - 1\right)}$$

I_m = Full Scale deflection Current
I_s = Shunt Current
I = Current to be measured
R_s = Shunt Resistance

Extension of range of PMMC Instruments

PMMC Voltmeter:-The range of a permanent-magnet moving coil voltmeter can be increased by connecting a high resistance R_s in series with it

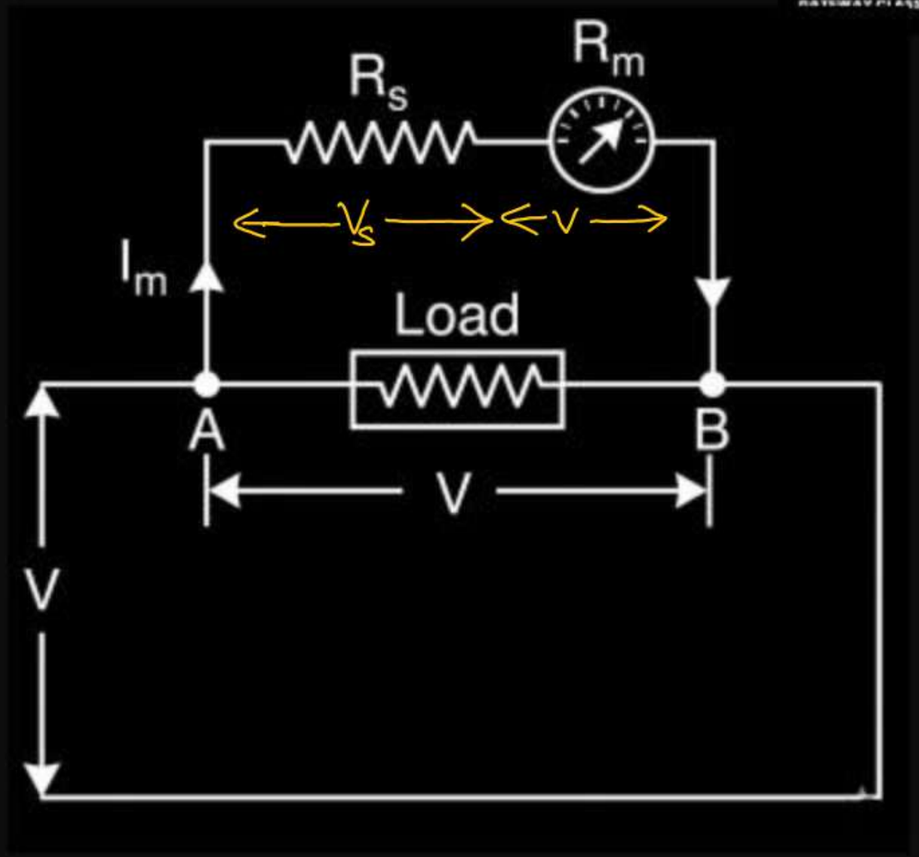
$$V = I_m(R_m + R_s)$$

$$V = I_m R_m + I_m R_s$$

$$I_m R_s = V - I_m R_m$$

$$R_s = \frac{V - I_m R_m}{I_m}$$

$$\boxed{R_s = \frac{V}{I_m} - R_m}$$



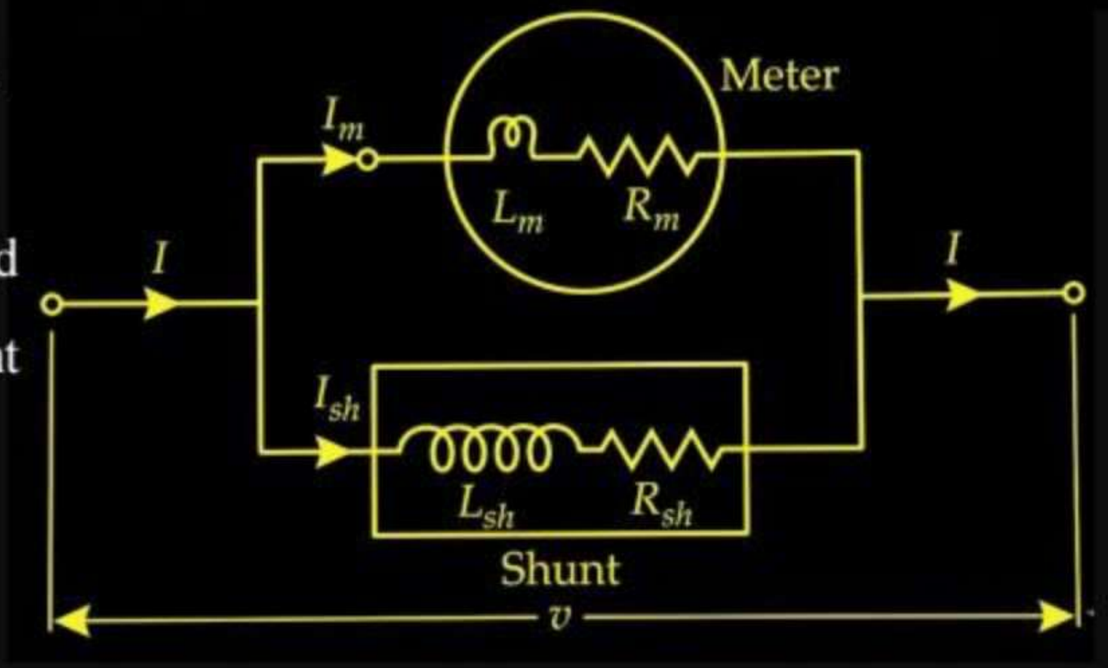
Errors in PMMC Instruments

In PMMC instruments the error occurs because of the ageing and the temperature effects of the instruments.

1. **Magnet –** The heat and vibration reduce the lifespan of the permanent magnet. This treatment also reduced the magnetism of the magnet.The weakness of the magnet decreases the deflection of the coil.
2. **Springs –** The weakness of the spring increases the deflection of moving coil between the permanent magnet. So, even for the small value of current, the coil show large deflection. The spring gets weakened because of the effect of the temperature. One degree rise in temperature reduces the 0.004 percent life of the spring.
3. **Moving Coil –** The error exists in the coil when their range is extended from the given limit by the use of the shunt. The error occurs because of the change of the coil resistance on the shunt resistance. This / happens because the coil is made up of copper wire which has high shunt resistance and the shunt wire made up of Magnin has low resistance.

Extension of range of MI Instruments

- Moving Iron instruments can be build for a range upto 50A.
- Hence shunt is not required except for very large current.
- If a shunt is required to be used with an ammeter to extend its range, the inductance of both the meter coil and shunt must be considered along with their resistance.



$$I_m Z_m = I_{sh} \cdot Z_{sh}$$

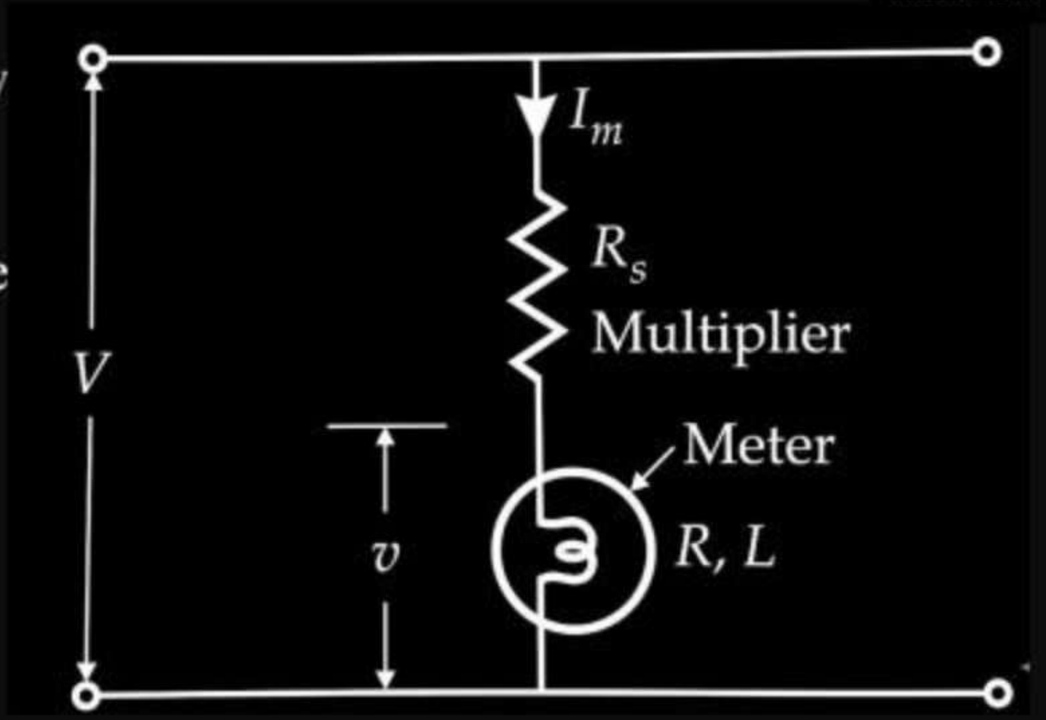
$$\frac{I_{sh}}{I_m} = \frac{Z_m}{Z_{sh}} = \frac{\sqrt{R^2 + (\omega L)^2}}{\sqrt{R_{sh}^2 + (\omega L_{sh})^2}}$$

$$= \frac{R}{R_{sh}} \sqrt{\frac{1 + \left(\frac{\omega L}{R}\right)^2}{1 + \left(\frac{\omega L_{sh}}{R_{sh}}\right)^2}}$$

To maintain $\frac{I_{sh}}{I_m}$ Constant $\frac{L}{R}$ ratio must be maintain.

Extension of range of MI Instruments

- Range of a moving-iron a.c. voltmeter is extended by connecting a high resistance (multiplier) in series with it.
- The combination is connected across the circuit whose voltage is to be measured.



Total Impedance $= \sqrt{(R+R_s)^2 + (\omega L)^2}$

$$I_m = \frac{V}{Z} = \frac{V}{\sqrt{(R+R_s)^2 + (\omega L)^2}}$$

$$V = I_m Z$$

Voltage multiplier

$$m = \frac{V}{v} = \frac{I_m \sqrt{(R+R_s)^2 + (\omega L)^2}}{\sqrt{R^2 + (\omega L)^2}}$$

Errors in MI Instruments

The various errors in the moving iron instruments are,

1) Hysteresis error : Due to hysteresis effect, the flux density for the same current while ascending and descending values İs different While descending, the flux density is higher and while ascending it is lesser. So meter reads higher for descending value of current or voltage. So remedy for this is to use smaller iron parts which can demagnetize quickly or to work with lower flux densities.

2) Temperature error: Errors can cause due to şelf heating of the coil and due to which change in resistance of the coil. So coil and series resistance much have low temperature coefficient Hence manganin is generally used for the series resistances.

3) Stray magnetic field error : The operating magnetic field in case of moving iron instruments İs very low. Hence effect of external to Stray magnetic field can cause error This effect depend on the direction of the stray magnetic field with respect to the operating field of the instrument.

Errors in MI Instruments

4) Frequency error : These are related to a.c. operation of the instrument The change in frequency affects the reactance of the working coil and also affects the magnitude of the eddy currents, This causes errors in the instrument.

5) Eddy current error : when instrument is used for a.c. measurements the eddy currents are produced in the iron parts of the instrument The eddy current affects the instrument current causing the change in the deflecting torque This-produces the error in the meter reading. As eddy currents are frequency dependent, frequency changes cause eddy current error,

Range extension of Electrostatic Instrument

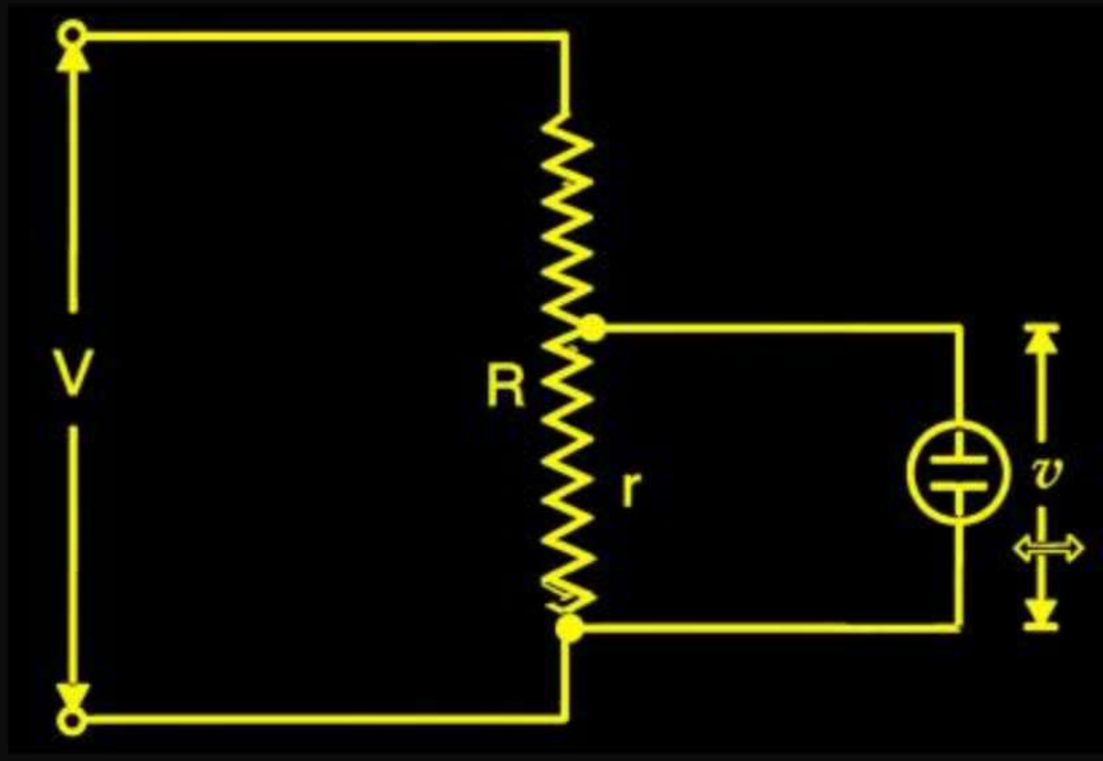
The range of electrostatic voltmeters can be increased by the use of multipliers. Two types of multipliers are employed for this purpose.

- Resistance potential divider - for ranges upto 40 kV
- Capacitance potential divider - for ranges upto 1000 kV

The first method can be used for both direct and alternating voltages whereas the second method is suitable only for alternating voltages.

Resistance potential divider:- This divider consists of a high resistance with tappings taken off at intermediate points. The voltage r 'to be measured is applied across the whole of the potential divider and the electrostatic voltmeter connected across part of it

multiplier $m = \frac{R}{r}$



Range extension of Electrostatic Instrument

Capacitance potential divider:- In this method, a single capacitor of capacitance C is connected in series with the voltmeter and the whole circuit is connected across the voltage V to be measured as shown in Fig. (b). Let v volts be the reading of the voltmeter. Since the voltage across a capacitor is inversely proportional to its capacitance,

$$C_t = \frac{C \cdot C_v}{C + C_v} \quad , \quad Z_t = \frac{1}{\omega C_t}$$

and $$V = I \cdot Z_t = I \cdot \frac{1}{\omega} \cdot \left(\frac{C \cdot C_v}{C + C_v} \right)$$

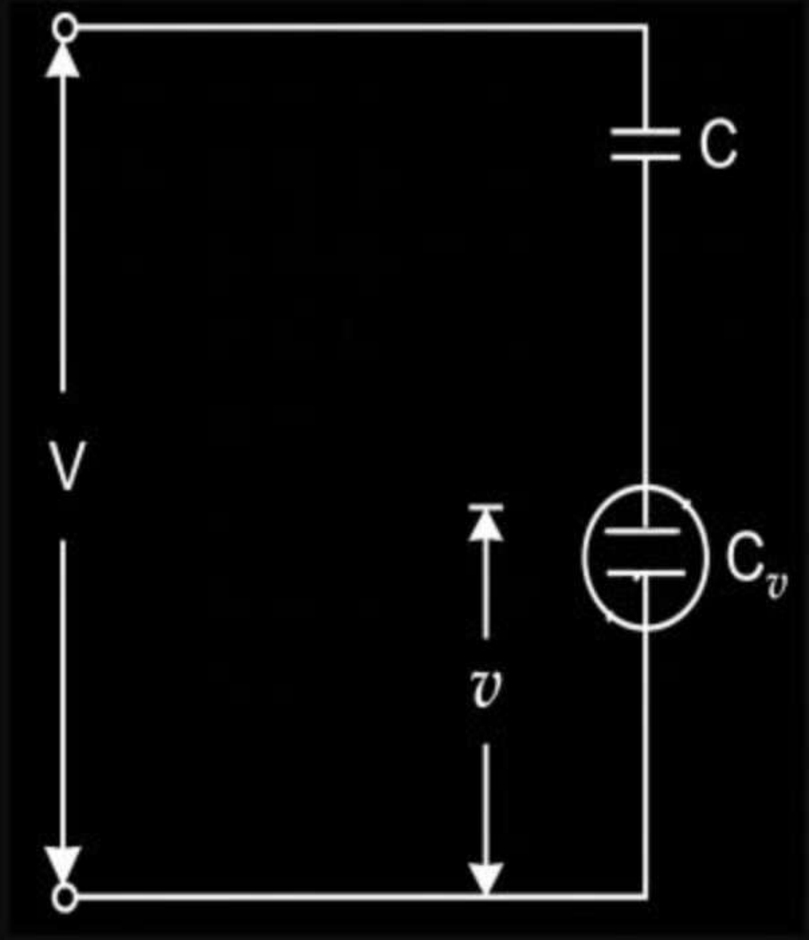
$$V = \frac{I (C + C_v)}{\omega C \cdot C_v} \quad \text{or}$$

$$V \propto \frac{C + C_v}{C \cdot C_v} \propto \frac{1}{C_v}$$

multiplier

$$m = \frac{V}{v} = \frac{C + C_v}{C}$$

$$\boxed{m = 1 + \frac{C_v}{C}}$$



Numerical Example

Example 4:- A moving coil ammeter has a full scale deflection of 50 μ Amp and a coil resistance of 1000 Ω. What will be the value of the shunt resistance required for the instrument to be converted to read a full scale reading of 1 Amp.

Sol. Full-scale deflection current of moving coil meter:

$$I_m = 50\ \mu A = 50 \times 10^{-6} A$$

•Coil resistance:

$$R_m = 1000\ \Omega$$

•Desired full-scale current:

$$I = 1\ A$$

Step 1: Calculate Shunt Current

$$I_s = I - I_m$$

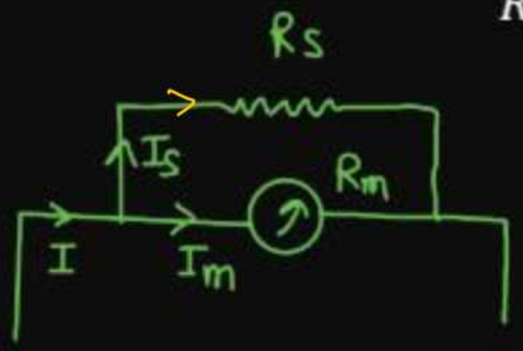
$$I_s = 1 - 50 \times 10^{-6}$$

$$I_s = 0.99995\ A$$

Step 2: Voltage Across Meter = Voltage Across Shunt

$$I_m R_m = I_s R_s$$

$$R_s = \frac{I_m R_m}{I_s}$$



Substituting the values:

$$R_s = \frac{(50 \times 10^{-6})(1000)}{0.99995}$$

$$R_s = \frac{0.05}{0.99995}$$

$$R_s \approx 0.050\ \Omega$$

Answer

$$\boxed{R_s \approx 0.05\ \Omega}$$

Therefore, the **shunt resistance required is approximately** 0.05 Ω**(50 mΩ)**.

Numerical Example

Example 5:- **The full scale deflection current of a meter is 1 mA and its internal resistance is 100 Ω. If this meter is to have full-scale deflection when 100 V is measured. What should be the value of series resistance?**

Sol. Full-scale deflection current:

$$I_m = 1\,mA = 0.001\,A$$

•Internal resistance of meter:

$$R_m = 100\,\Omega$$

•Desired voltmeter range:

$$V = 100\,V$$

Step 1: Calculate Total Resistance Required

For a voltmeter,

$$R_T = \frac{V}{I_m}$$

$$R_T = \frac{100}{0.001}$$

$$R_T = 100000\,\Omega = 100\,k\Omega$$

Step 2: Calculate Series Resistance

$$R_s = R_T - R_m$$

$$R_s = 100000 - 100$$

$$R_s = 99900\,\Omega$$

$$\boxed{R_s = 99.9\,k\Omega}$$

Therefore, a series resistance of 99.9 kΩ is required to convert the meter into a 0–100 V voltmeter.

Numerical Example

Example-6 **A moving coil ammeter gives full scale deflection with 15 mA and has a resistance of 5 Ω. Calculate the resistance to be calculated in (a) Parallel to enable the instrument to read upto 1 A (b) Series to enable it to read up to 10 V. [UPTU 2002]**

- Full-scale deflection current $I_m = 15\,mA = 0.015\,A$
- Meter resistance: $R_m = 5\,\Omega$

(a) Shunt Resistance for 1 A Ammeter

Desired current range: $I = 1\,A$

Step 1: Calculate Shunt Current

$$I_s = I - I_m$$

$$I_s = 1 - 0.015 = 0.985\,A$$

Step 2: Apply Current Divider Relation

Voltage across meter = Voltage across shunt

$$I_m R_m = I_s R_s$$

$$R_s = \frac{I_m R_m}{I_s} = \frac{0.015 \times 5}{0.985}$$

$$R_s = \frac{0.075}{0.985} \approx 0.076\,\Omega$$

(b) Series Resistance for 10 V Voltmeter

Desired voltage range:

$$V = 10\,V$$

Step 1: Calculate Total Resistance Required

$$R_T = \frac{V}{I_m}$$

$$R_T = \frac{10}{0.015}$$

$$R_T = 666.67\,\Omega$$

Step 2: Calculate Series Resistance

$$R_{series} = R_T - R_m$$

$$R_{series} = 666.67 - 5$$

$$\boxed{R_{series} \approx 661.7\,\Omega}$$

→ What is measurement
→ Classification of Error
→ PMMC, MI, Induction
→ Characteristic.

} ← Important

Gateway Classes

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